buildings

MDPI

Article

Characteristics of Smart Farms for Architectural Planning and Design

Donghwa Shon [1], Eunseok Lee [2], Yejin Lee [1], Jieun Lee [1] and Nahyang Byun [1,*]

1 Department of Architecture, Chungbuk National University, Cheongju 28644, Republic of Korea
2 Architecture & Urban Research Institute, Sejong-si 30103, Republic of Korea
* Correspondence: nhbyun@chungbuk.ac.kr

Abstract: In the 21st century, humanity is facing unprecedented climate and food crises caused by population growth, urbanization, environmental pollution, and carbon emissions. As a response to the climate and food crisis, the following concept has emerged: smart urban agriculture that can reduce carbon emissions from buildings and achieve self-sufficiency in food. Various architectural designs that include smart farms are being explored worldwide. Nevertheless, the concept does not seem to have gained sufficient popular traction. This study attempted to materialize the concept by presenting types and characteristics from an architectural planning and design perspective by examining cases of smart farm constructions worldwide. After collecting 171 smart farm cases from around the world and building a database in terms of city, architecture, environment, and crops, the types were classified through SOM analysis, an artificial neural network-based cluster analysis methodology. As a result of the analysis, smart farm types were classified into seven types, and the characteristics of architectural planning and design were extracted for each type. It is meaningful that a specific form was presented so that planning and design can be easily accessed according to the situation placed through the type of smart farm.

Keywords: urban agriculture; smart farm; architectural planning; architectural design; carbon neutrality; self-organizing map; typological analysis

Citation: Shon, D.; Lee, E.; Lee, Y.; Lee, J.; Byun, N. Characteristics of Smart Farms for Architectural Planning and Design. *Buildings* **2023**, *13*, 93. https://doi.org/10.3390/buildings13010093

Academic Editors: Miguel Amado, Francesca Poggi and António Ribeiro Amado

Received: 28 November 2022
Revised: 12 December 2022
Accepted: 27 December 2022
Published: 30 December 2022

1. Introduction

1.1. Background

In this century, society is facing climate and food crises. The world's population is growing rapidly with an aging population. More than half of the world's population lives in cities [1,2]; this rapid urbanization leads to increased environmental pollution [3–6] and carbon emissions caused by poor development and population concentration, and decreased agricultural land that has been taken over by urban expansion [7–10]. In addition, as the aging population increases, the population that is involved in agriculture decreases, which is expected to cause problems in food supply stability [1,7–10]. The problem of global warming caused by carbon emissions further accelerates the threat to food security. Climate change is causing abnormal climatic conditions, such as droughts, floods, abnormally high temperatures, and a rise in sea levels throughout the globe. These conditions significantly impact crop production [1,8–11]. The recent COVID-19 pandemic and the unstable international situation, such as the wars in Eastern Europe, have revealed food transportation and distribution problems, further heightening the severity of food security [12–14].

Climate and food crises are expected to intensify, and the concept of urban agricultural smart farms is emerging as a way to overcome them [8–10,15–23]. The goal is to create an effective environment for crop production with smart technology by providing a space for producing crops on the inside or outside of rooftops on buildings. This strategy can promote the production of crops that can be self-sufficient in an urban environment.

Urban agricultural smart farms offer several benefits, such as recycling a building's energy and reducing load, maximizing crop production and minimizing manpower through smart technology, reducing transport energy due to self-sufficiency, stabilizing food supply and demand, and revitalizing local communities. Most rooftops of buildings in urban areas are often left empty. Installing a smart farm using the rooftop space can suppress the heat island phenomenon that causes buildings to become hot. Techniques such as roof greening can reduce the load on heating and cooling inside the building. There are many advantages in energy utilization if the waste heat and carbon dioxide emitted from the building's heating and cooling facilities are not thrown away and used in connection with the smart farm. By creating an environment optimized for plant growth through smart sensors, crop production can be maximized, and the problem of manpower shortages due to aging can be overcome because crop growth is maintained through an automated system. Most crops produced by the smart farm can predict a certain amount of productivity. Production costs can also be lowered because the distribution stage is unnecessary. Programs such as rest, eating, education, production, and sales can be provided for each building type, and programs linked to the local can contribute to the revitalization of regional boundaries.

It is clear that if urban agricultural smart farms become common in cities worldwide, they will contribute to reducing carbon emissions and stabilizing food supply and demand. Nevertheless, there have been several limitations to the worldwide growth of smart farm popularity. Several problems, such as the return on profits compared to investment facilities, need to be addressed. One of the reasons that smart farms have not yet found their footing as a popular form of architectural planning and design is that it is still a newly emerging concept. This is because, in addition to designing a simple greenhouse, an understanding of smart technology and knowledge related to crop growth is required. Accordingly, this research aims to help practically materialize smart farms by analyzing the characteristics of the different types of smart farm construction cases around the world.

1.2. Questions and Goals of the Study

The questions in this study are as follows.

- What kind of architectural existence does the smart farm show by type?
- What are the architectural planning considerations for the dissemination and diffusion of urban smart farms?

The purpose of this study is to present the architectural types of smart farms worldwide and identify their characteristics. In order to understand the concept of smart farms that have yet to become common, it is necessary to understand the architectural concept through case analysis of current smart farms. The tangible approach shown in the case can help understand the architectural concept of smart farms and contribute to the spread of smart farm architecture.

1.3. Materials and Methods

The study is conducted in four stages: case collection, DB construction, SOM analysis, and tangible characteristics.

First, 171 cases of smart farm architecture worldwide were collected through literature and websites. Regional and urban characteristics were identified through map or aerial photo information. The background, program, facility, plant, and operation method of the case were collected through the website. The architectural characteristics were identified through image information.

The second collected cases were divided into four perspectives: "City," "Architecture," "Environment," and "Crops," and architectural planning and design elements were constructed as DBs. DB was built from the perspective of architectural planning and design of smart farms, and DB was designed to explain cases well from the perspective of form and function.

Third, a self-organizing map (SOM) analysis was conducted on the case DB. Seven types were derived that can optimally explain the entire case. SOM preserves the hierarchy of multivariate variables with a neural network-based clustering analysis methodology, so it is possible to explain the characteristics of the type clearly. It is output as a U-Matrix classifying type and a Plane Map describing each variable. It is a data mining technique that intuitively represents data and is applied in various fields.

Finally, representative examples and architectural characteristics by type were presented.

2. Theoretical Background

2.1. A Crisis That Threatens Human Survival

The crises of climate change, environmental pollution, population growth, urban concentration, war, infectious diseases, and food crises do not operate independently but are mutually influenced, and the risks they bring together are becoming increasingly serious.

The climate crisis caused by global warming is perhaps the most serious. Greenhouse gases emitted by fossil fuels have caused global warming, and the temperature rise is creating environmental conditions that are difficult for humans to live in, such as drought, water shortage, fire, sea level rise, heat waves and storms, and a decrease in biodiversity [24]. Some countries are losing their homes due to sea level rise. If global warming continues, most countries' low-lying coasts are expected to be submerged [25]. Rising sea levels will reduce human habitable land and agricultural land and increase global population density. To develop strategies to slow down and prevent climate change, 196 countries signed a long-term agreement to keep the temperature rise below 1.5–2 degrees Celsius compared to pre-industrial levels through the Paris Agreement of the UN Climate Change Conference (COP21) in 2015 [26]. However, although each country is establishing a plan to reduce carbon emissions, it is expected that even if those country-specific targets are achieved, there will be difficulties keeping the temperature rise in check [27].

Problems with population growth and deepening urbanization are also emerging. The world's population has increased rapidly since 1950 and has reached 8 billion in 2022. Although the population growth rate is decreasing, the overall population is still expected to continue to grow to 10 billion by 2050 [1]. It is projected that by 2050, 70% more food will be needed to meet the demands of the growing population [1]. Urbanization is accelerating, and 55% of the world's population lives in cities. The rate of urbanization by continent is as follows: Africa (42.5%), Asia (49.9%), Europe (74.5%), Latin America (80.7%), North America (82.2%), and Oceania (68.2%). In Asia and Africa, urbanization and population numbers are rapidly increasing [2]. As urban areas expand, agricultural land decreases, and the crop-producing population continues to decrease. The food supply to meet the food demand is also becoming unstable [8–10].

Farmland area has decreased by half (0.23 ha) since 1961 [7]. The recent rise in sea levels caused by climate change is expected to further reduce the global land area [28]. Agricultural land has already been greatly reduced due to floods and droughts [1,7–11].

As populations become concentrated in cities, the ones in rural areas gradually decrease. In countries where the aging populations are increasing, it is expected that there will be difficulties in the population that have the physical capacity to produce crops [2].

Urbanization also affects environmental pollution and carbon emissions [3–6]. As environmental pollution continues, the problem of contamination of crops produced on farmland is also becoming a common issue. Therefore, countermeasures for supplying healthy and fresh food are required [1].

Most countries produce crops on farmland far from the city or import grains from abroad. However, this process emits considerable carbon in correlation to the increase in transport distances [29]. This method not only exposes problems in carbon emission but also affects food supply and prices if there is a problem in distribution or transportation. Due to the recent COVID-19 outbreak, border closures and social functions have been paralyzed, causing difficulties in crop production and disruptions in transportation and distribution [12–14]. The 2022 Ukrainian–Russian war has caused food supply disruptions and a rise in global oil prices [30,31]. Since Ukraine and Russia produce a significant portion of the world's wheat, maize, and barley, countries that depend on them for grain imports have suffered considerable food shortages [31].

2.2. Concept of Urban Smart Farm

The ongoing climate crisis and food crisis suggest the necessity for urban agriculture. Many scholars have cited smart urban agriculture as having social, cultural, economic, and environmental benefits. The concept of a smart farm is a relatively recent term. In the past, the term urban agriculture was more commonly used.

The concept of urban agriculture is an extension of vertical agriculture. The term vertical farming first appeared in 1915 by Gilbert Ellis Bailey, who suggested the benefits of hydroponics in a controlled environment [32]. The underlying concept of precision agriculture appeared in the mid-1980s, starting with the study of the agricultural production system based on the optimal region, the optimal time, and the optimal prescription ('Doing the right treatment, at the right times, in the right place'). In 1988, Patrick Blanc presented a patent for growing plants using felt material instead of soil [15]. Then, in the early 2000s, the concept of vertical agriculture was established by Dickson Despommier. Vertical agriculture is a vertical farm designed to produce many crops on a small piece of land for a stable food supply in response to population and urban expansion [8–10].

As the internet of things (IoT) concept is applied to urban agriculture, precision agriculture enables effective crop production with less labor and energy use [33,34]. For example, to create an optimal environment for plants to grow, sensors, digital controllers, and control systems are connected through a network to build an automated agricultural environment [35]. Even without the experienced farmer's knowledge, it is possible to create an optimized environment for crop growth based on data and to maximize production efficiency [36]. Artificial intelligence technology, which has grown rapidly since the 2000s, can be applied to smart farms using IoT to bring out their potential [37–39].

Currently, smart agriculture is largely divided into four categories: (1) traditional soil cultivation; (2) hydroponics that supply nutrient liquids to crops; (3) aeroponics that enables plant growth with mist; and (4) aquaponics that utilizes the symbiotic relationship between fish and plants [15]. As smart technology is applied, these methods are automated through sensors, digital controllers, and control systems.

2.3. Necessity of Urban Smart Farm

The benefits of urban agriculture are generally presented as advantageous to social, economic, and environmental contexts [16–18].

The social advantage is that it can promote physical and mental health through urban farming activities. Fresh crops can be secured, [19,20] and community-oriented activities help social participation and local community solidarity and can create secondary effects such as local attachment and safety [15]. It can improve the public space of the local community through landscape design [15,17,21,22]. It can also be used to create a human-friendly space for rest, recreation, and educational activities in the city [23]. Community-centered activities help social participation and solidarity within the local community and can create secondary effects, such as regional attachment and safety [15].

Economically, urban agriculture businesses can create local employment opportunities [22,40,41]. It can also contribute to the stability of food prices that have been affected by international situations, climate change, urbanization, war, and disease [20]. As it is cultivated in a controlled environment, it is possible to produce more efficiently in terms of time and labor than natural cultivation [7–11,42]. In particular, it is very effective in urban areas with high land density because it can produce a variety of crops using a small amount of land [7–10]. By improving the existing transportation system and reducing transportation time and cost, it is expected that about 60% of the cost can be saved [33].

Environmentally, reducing carbon emissions through the urban heat island phenomenon and energy recycling is possible [8–10,15–17,43,44]. When a green space or greenhouse is installed on the roof, it reduces the absorption of solar energy in summer, reducing the cooling load by about 10 to 40% [45–47] and reducing the internal heat loss of the building in winter [48,49]. When a greenhouse is installed in a building, it is possible to use carbon dioxide or waste heat generated from heating and cooling facilities as an energy source for plant growth. If the green area increases, the quality of harmful air can be improved, the energy load of buildings can be reduced, and noise can be absorbed [15]. Crops produced in a controlled environment can be grown in an uncontaminated, clean environment [15,42], unaffected by climatic conditions [50]. Since crops are supplied locally, the carbon emission caused by the generation of transportation energy to move crops from distant farms to urban areas can also be greatly reduced [42,50].

As smart technology is applied, the aforementioned benefits of urban agriculture can be maximized [51]. By optimizing the water supply, heating, and cooling energy, precision agriculture that minimizes energy resource consumption but maximizes production became possible [33,34]. In a situation where there is a shortage of agricultural workforce caused by the increase in the elderly population, the agricultural automation system based on smart technology not only solves the workforce problem but also enables the general public, who lack the agricultural knowledge, to easily produce agriculture [36].

2.4. Prior Research on Smart Farm Construction Types

Smart farms, which have emerged as an alternative to solving urban and environmental problems, demonstrate their value by being applied to urban agriculture. More than 20 years have passed since the smart farm concept first appeared in the early 2000s. However, a transparent architectural concept has not been established yet. Most preceding studies suggest the necessity for urban agriculture as a solution for environmental and population problems. They have also studied smart farms' operation methods and efficiency from the perspective of sensing and control technology. However, little research on architectural concepts, plans, and designs has been conducted.

Urban agriculture is not limited to smart farms and deals with comprehensive agricultural activities in urban areas. Zaręba et al. [15] presented the positive effects of urban vertical farms at various scales on local communities' social, economic, climatic, and financial benefits. Haung et al. [52] presented the feasibility of rooftop farms in high-density urban areas through a model that can expect maximum crop production with minimum irrigation resources. The research was conducted to point out the difficulties in the spread of the popularity of urban agriculture, despite its advantages. Hardman et al. [53] presented economic, soil quality, and facility maintenance difficulties in urban agriculture and suggested ways to overcome them. Ivascu et al. [54] presented the degree of contribution to adopting urban agriculture ideas regarding confidence, society, pleasantness, and naturalness. Grebitus et al. [55] investigated local communities' environmental, social, economic, and food-related perceptions about adopting urban agriculture. Martellozzo et al. tried to estimate the number of crops that could be produced in urban areas by using global city data in a situation where most of the population is concentrated in urban areas [56].

The study deals with the architectural concept of smart farms as urban agriculture and considers operating methods and morphological types in the construction process but does not suggest specific plans or design directions. Fallmann et al. [57] suggested that responding to climate change from the urban or architectural perspective would be important. Krikser et al. [58] presented the characteristics of three types (Ideal Type, Subtypes, and Mixed Types) from three perspectives (self-supply, socio-cultural, and commercial) that provide a support structure for practical decision-making in urban agriculture. Zaręba et al. [15] presented considerations for architectural techniques, such as modular panels, container systems, and living walls in vertical agriculture. Korea, which has high population density and urbanization, also has increased interest in smart farms using urban buildings. Korea proposed five spatial types (residential building type, neighborhood type, city centers type, farm or park type, and school education type) for urban agriculture while implementing the Act on Development and Support of Urban Agriculture [59]. Oh et al. [60] derived satisfaction with the five types of urban agriculture suggested by the Act and presented policies and factors that affect them.

2.5. Application of SOM for Structural Typological Analysis

Classifying multiple smart farm cases into several types may lead to different results because the criteria for classification vary depending on the researcher. As the number of explanations for the architectural plans and design features of smart farm cases increases, it is difficult to classify them objectively. It is necessary to secure objectivity through a quantitative cluster analysis method and classify according to the objective criteria of the data. There are various types of quantitative cluster analysis methodologies. Still, among them, we want to apply an artificial neural network-based SOM analysis method that preserves the hierarchy of high-dimensional variables and visually expresses the cluster analysis results [61–64]. This method has the advantage of understanding the representative types of smart farms and the planning and design characteristics that contribute to them.

Kohonen, T. devised the SOM method, which makes it possible to visualize data by non-linear projection based on an unsupervised learning single-layer neural network consisting of an input layer and an output layer [61–64]. The result is output as a two-dimensional map composed of grid or polygon nodes [61–64]. Each node has a weight vector value and exhibits self-organization characteristics with properties similar to neighboring nodes [61–64]. Since this map preserves the hierarchy of high-dimensional data with a non-linear structure, it is easy to understand the relationship between variables and types [65]. Various attempts have been made to verify the reliability of the SOM methodology [66]. As it is effective in feature extraction and classification, it has been applied to various fields, such as biology, climate and meteorology, medicine, engineering, ecology, data science, IT, and architecture [65,67].

Although there are not many cases where SOM methodology has been applied in architecture, there have been attempts to classify building types. Park et al. classified the characteristics of resident behavior according to the type of dwelling [68]. Shon et al. presented the types and characteristics of residents' housing satisfaction concerning the physical environment of housing through SOM [69]. The characteristics of traditional city streets and exteriors of buildings were also presented by classifying them through SOM [65,70].

3. Representative Types through Case Analysis of Smart Farms

3.1. Worldwide Smart Farm Cases and Analysis Criteria

Smart farm construction cases from around the world were collected through the literature and the Internet. Data about the related websites, articles, and photos were collected, the information was checked using Internet searches, and the buildings and surroundings were checked based on their addresses. The collected cases were classified into four aspects of cities: architecture, environment, crops to explain architectural planning, and design characteristics. It was divided into 47 major categories according to the four criteria of city, architecture, environment, crop, and data values that can explain the cases that were entered for each category (Table 1). The 47 classification criteria were selected as items that could affect smart farm construction, and information that could not be collected from the website or the literature was excluded. The information related to cities was input from the surrounding environment, region, and urban scale of smart farm cases. The information related to the architecture was input about the size, construction year, application location, construction, structure, materials, and building programs. The environment was input for eco-friendly planning techniques and facilities related to smart farm buildings, and the plant was input for the type and method of plant growth.

Table 1. Criteria for Classifying Smart Farm Cases.

Class	Main Category	Subdivision
Urban	Nearby green area	Existence/non-existence
	Nearby width of road	3 to 42m
	Specific use district	Residential/Commercial/Green/Manufacturing Area
	Nearby Density	Low density with non-skylighting/High density
	Urban area	with skylighting
	Urban density	0 to over 100,000 km^2
	city population size	0 to over 100,000 person /km^2
	Ratio of Agricultural	less than 50,000 to more than 10 million
	Population *	City Ranking
	Food self-sufficiency rate *	City Ranking
	Urban Climate	Tropical/Temperate/Cold/Cold/Dry
	City Income	<0.60/0.60-1.65/1.65-2.76/2.76-5.06/>5.06
	Agricultural GDP *	City Ranking
	Urban Land Price *	City Ranking
Architecture Environment Control Plant	Lot Area	0 to over 100,000 m^2
	Total Floor Area	0 to over 100,000 m^2
	Stories *	-
	Construction Year *	-
	Smart-farm Total Floor Area	0 to over 10,000m^2
	Smart-farm Stories *	-
	Size of smart farm	Small/Medium/Large Size
	Smart-farm application location	Part of the building/Whole building
		Rooftop/Ground Floor/Basement
	Smart farm applied part	Interior Space/External roof/External Terrace/
	Application space	External Wall
	Smart farm installation method	New construction/Existing building
		Business/Residential/Commercial/Factory/
	Uses other than smart farm	Education/Research/Etc.
	Program	Growth room/Exhibition/Education/Sales/
	Building type	Experimental/Office
	Growth area ratio in smart farm	General architecture/Temporary
		construction/Non-building
	Structure	Under 20%/20–50%/50–80%/80% over
	Smart farm construction method	RC Wall/RC Ramen/SRC/S/Light Steel/Wood/Etc.
		Dry/Wet/Pre Fab.
	Column protrusion	External protrusion/External non-protrusion
	Smart-farm floor height	Under 3m/3m to 6m/6m to 9m
	Smart-farm Elevation	Under 20%/20–50%/50–80%/80% over
	Window Area Ratio	On building/Metal bonding/RC bonding/Weld
	Bonding method with building	bonding/Integral type
		Fixed and non-movable/Assembled and Attached
	Mobility of smart farm	Move
	architecture	Y/N
	Smart-farm insulation	Column, beam/finished product/Plan
	modularity element	Glass/Brick/Aluminum/Stone/Wood/
	Finishing material	Concrete/Steel/Etc.
	Smart-Farm Passive	Rainwater/Shape/Atrium/Plant/Insulation
	Technology	Solar heat/Light of the sun/Geothermal heat
	Smart-Farm Active	Integrated monitoring/Temperature,
	Technology	humidity/Air/Moisture
	Environmental control	Centralized/Individual
	Smart-Farm System Elements	
		Plants/Gardening/Craft
	Productive crop	Soil/Hydroponic/Aquaponics
	Cultivation method	Natural light/Artificial light/Water supply/
	Growth method	Rainwater
	Planting module	Y/N
	Vertical Growth Density	1 Level/2 Level/3 to 10 Levels/over 10 levels

* The variables displayed were set on a ratio scale, and the rest were on a nominal scale.

Cases for which information could not be obtained according to the four criteria of the survey method were excluded from the analysis, and 171 cases were finally targeted. The study aims to derive the architectural planning characteristics of urban smart farms. However, the cases were collected without distinction between urban and suburban areas.

3.2. Classification According to U-Matrix

Currently, SOM analysis can be performed using various platforms. However, a commercial analysis program, Viscovery® SOMine®, was used in consideration of the reliability of analysis results and the visual representation of data [71]. SOM analysis allows the creation of a map called a U-Matrix, representing all types of clusters [71]. The area of the cluster shown in this map represents the number of cases as an area ratio and represents the adjacent properties of similar properties [69–71]. The optimal number of clusters can be selected through the Dendrogram results.

The clustering results for smart farm cases show seven clustering results (Figure 1). Seven types were derived by comprehensively considering the area ratio of cases by cluster and the distance of clusters. The U-Matrix is a map showing the areas of seven clusters, and the number of cases in each cluster is C1 (43 Cases), C2 (31 Cases), C3 (29 Cases), C4 (22 Cases), C5 (24 Cases), C6 (15 Cases), and C7 (7 Cases) are shown. C1 is located in the center of the map and is adjacent to most types, so it has similar characteristics to clusters except C7. However, since the clusters located at the edges with C1 in the middle are not adjacent to each other, there is a distance in similarity. The distance between C5 and C7 is the farthest, showing a large difference in similarity. The results representing the characteristics of the seven clusters are illustrated in Figures A1–A7.

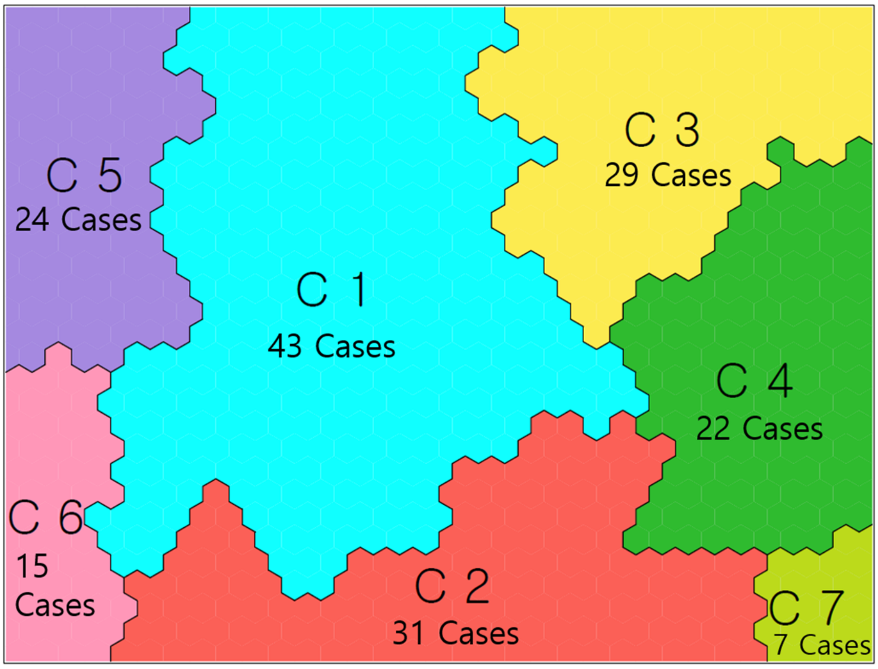

Figure 1. U-Matrix for 171 smart farm cases.

3.3. Type Characteristics through the Relationship between Plane Map and U-Matrix

The plane Map is a map that visually shows the characteristics of all variables for the entire cluster of U-Matrix and can identify the relationship between variables and clusters [71]. Figure A8 is a Plane Map for all 290 variables in the Plane Map: the area of the cluster is indicated by a line, and the characteristics of the variable are indicated by a red area (Figure 2). Figure 2, which shows a part of the Plane Map, will be explained as an example. variable of 'Lot Area (m^2): For the 2000–5000′, the red area occupies a slightly dispersed area in most clusters, and it is difficult to explain the contribution or characteristics of a specific cluster. The second variable, 'Mobility of smartfarm: Fixed and non-movable', accounts for about half of the total cluster. Most of them appear in the C3 cluster, and about half appear in the C1 cluster. The third variable, 'Mobility of smartfarm: Assembled and attached move', is distributed in the opposite area to fixed and non-movable variables. This is because the variable of 'Mobility of smartfarm' is divided into two nominal variables. Finally, the 'Nearby Density: High density with Skylight' variable is intensively distributed in C2, which shows that this variable contributes to forming the C2 cluster.

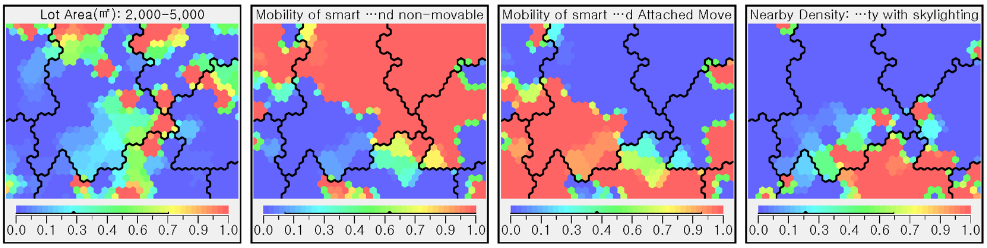

Figure 2. Part of the result of Plane Map.

If the clustering area of the U-Matrix and the area occupied by a specific variable in the Plane Map coincide, it can be said that the contribution of the specific variable to the clustering is high. The correlation between variables can be identified by comparing the occupied areas between variables in the Pane Map and analyzing the degree of similarity.

The variables with a high contribution form the seven types. Among various variables, the variables contributing to type formation can be identified quantitatively. However, not all 47 variables contribute to cluster formation. Several variables contribute to the type, but most do not. The variables that do not contribute to the type appear regardless of which type, so they cannot be said to be a feature.

The characteristics of the seven types of smart farms can be intuitively understood through the relationship between the U-Matrix and Plane Map. An easier representation of their relationship can be seen in Figures A1–A8. The relationship between the U-matrix and Plane Map can be understood through the graphs, and the characteristics of the seven types are described according to the analysis results.

4. Characteristics of Architectural Plans and Design

4.1. Characteristics and Representative Cases of Smart Farm by Type

C1 is a glass-building greenhouse-type smart farm. It accounts for the largest proportion of all cases. Since the plan optimized for plant growth was made from the initial building stage, the area and density used for plant growth are high. Glass finishing materials are often used for steel structures to utilize solar radiation actively. As a building for plant growth, smart facilities, such as heating and cooling facilities, water supply, and growth monitoring systems, are systematically and actively applied. The C1 type is being built regardless of whether it is in a downtown or suburban area. In suburban areas, it is being built in a single story on a large site. In downtown areas, it is built consisting of two floors, but the surrounding density is relatively low. These types often include functions such as commerce and education, education and research.

Gotham Greens was built in Yolo County, CA, USA, in 2021 and has a relatively large land and building area as it is located in a suburban area [72]. It provides educational practice to students at nearby universities and supplies agricultural products to nearby cities and the state of California [72]. It is a single-story building. In contrast to this, the production rates in high-rise glass greenhouses are increased by harvesting crops 20 times a year through hydroponic cultivation [72]. As environmental control and hydroponics are achieved through smart technology, water resource saving, energy use, and production efficiency can be maximized [72]. Vertical harvest Jackson is an example of a multi-story building built in Jackson, WY, USA [73]. Although it is a small city with a population of about 9,000, it is located in the downtown area. This building is planned in relation to housing, retail, and community facilities and is a three-story greenhouse. Since it is a duplex, there is an atrium that allows light to flow into each floor, and artificial lighting is also used for spaces lacking natural light. Plant growth beds are configured in multiple stages to increase production efficiency, and various crops are produced depending on the space [73]. The space is characterized by an operating method that aims to contribute to the local community, such as hiring the socially underprivileged in the region and supplying crops to the region [73].

C2 is an indoor small smart farm. Most of these cases are located in dense urban areas and are often operated on a small scale of less than 500 square meters. Since crops are cultivated in areas with high urban density, they are cultivated using unused space within buildings or container boxes. Since natural light is difficult to grow indoors, artificial lighting is often used. Therefore, glass materials are rarely used for the exterior. While the C2 type is difficult to mine, it has the advantage of maintaining a uniform environment. Environmental control is achieved by actively utilizing smart facility systems for environmental control and growth, such as artificial lighting, temperature and humidity, airflow, and nutrient solution control systems. The growth density is, therefore, high because crop production is performed in a limited space.

Metro Farm is located inside the Sangdo Station in Seoul, Republic of Korea. Although the area is not large, a smart farm was created by utilizing unused space in the station. Since the underground space in the subway cannot receive sunlight, it is very dependent on environmental control facilities. Therefore, metro Farm controls the artificial lighting, temperature and humidity, and the airflow environment and actively utilizes smart technology related to plant growth [74]. It aims to maximize the production rate of crops by uniformly controlling the indoor environment. Although small, there are research and processing spaces, education and experience spaces, cafes, and sales spaces in addition to the growing space [74]. The unused space is utilized at an affordable price, and the accessibility of subway users is good, so it is advantageous from a business perspective to sell fresh salads.

C3 is a type of rooftop urban agriculture. In many cases, gardens or glass greenhouses are installed on the rooftops of buildings in urban residential areas. In many cases, ornamental plants and vegetable plants are produced together. Since the purpose of community formation for residents, leisure and hobby, and small-scale self-sales are made, the plant growth density is low: for example, a plant growth space may be only on a single level. Lightweight soil is used for ornamental plants in building rooftop gardens, but Aquaponics or Hydroponic methods are also used for vegetable growth. However, the dependence on the facility system for environmental control is small. As it is installed on the roof of a building, it actively accepts sunlight by using a steel frame structure and glass exterior.

Jardins perchés de Tours is an example of a farm set up on the roof of an apartment building in Tour, France [75]. It was planned as an experimental project combining social rental housing and farms. A farm is being prepared on the roof and ground of the building, and residents intend to revitalize the community through agriculture [75]. The glass greenhouse installed on the roof of the building is made of a single layer. Crops are grown through hydroponic cultivation and are composed of monolayers. Because the purpose is to activate the community of residents, the growth density of crops is low. Part of the rooftop space has space for rest and education, and education and sales for residents are conducted by agricultural experts.

C4 is a smart farm with a vertical extension of the building. The location of the glass greenhouse smart farm on the roof of an urban building is the same as C3, but the difference is that it is large and has a high production area and density (number of bed floors) for production and sales. Smart facilities are being actively applied for high crop yields. The harvested crops are served at local restaurants in buildings or sold at commercial facilities.

Verticrop is located on the roof of a parking lot building in downtown Vancouver, BC, Canada [76]. Utilizing the roof space of an underutilized parking lot in the city center, we tried to increase the utilization of the space and secure a locational advantage. The greenhouse is tall, and the crop growth bed is densely constructed. It is a system in which the bed moves through a conveyor for the efficiency of crop growth and management. The temperature, lighting, and water supply are automated for minimum energy use and maximum harvest [76]. Crops grown here are sold locally.

C5 is a factory-type smart farm. It is similar to C1 as the entire building is used as a space for crop production. The important difference is that it has a high growth density (number of bed layers) to maximize crop growth and controls the indoor environment by blocking the external environment. A steel frame structure was used to form a large space, and the indoor environment was controlled using opaque exterior materials and insulation materials that cannot transmit light. Therefore, the indoor environment is controlled by artificial lighting, temperature and humidity, airflow, nutrient supply, and an integrated control system. Although located in cities, most cases of this type of building are distributed in areas with low urban density because large-scale growth spaces are required.

The Spread Kameoka Plant was built in Kyoto, Japan, in 2006 [77]. It is a large single-story building on a large plot of land in the suburbs. The interior space is not lit and forms a large space with no pillars and a high floor height. Growing trays are placed in high-density, and mechanized facilities control the environment and manage crops. The goal is to maximize productivity and profitability, and the annual crop of 770 tons is supplied to markets throughout Japan [77].

C6 is a suburban smart farm. The entire building is used as a space for growing crops and is similar to the C1 type, as the site area and growing space are very wide. The difference is that it is made of a single story using lightweight steel frames or temporary building structures. It is a type of architecture distributed in suburban farms, and various smart technologies are introduced depending on the cultivation method and crop depending on the case site. It is mainly distributed in small cities or suburban areas and has an extensive growing space.

C6 is a farm created by Jinan-Gun, a local government in Korea. A glass greenhouse was built using lightweight steel frames and glass finishing materials in a building area of 1.6 ha [78]. This structure is a greenhouse used primarily in rural areas in Korea, and both soil and hydroponic cultivation are performed. In addition, smart technology that manages temperature, humidity, light, carbon dioxide, soil, etc., is being introduced to existing agricultural facilities [78].

C7 is the Greenwall high-rise building. In these cases, planting materials were applied to the exterior of buildings for eco-friendly, ecological, and aesthetic purposes rather than for crop growth. The plant-occupied area is a large part of the exterior of the building, created by placing space for plant growth on the walls or balconies of the building. These types do not use smart sensors or equipment systems significantly, and there are few cases of growing edible crops, such as vegetables. In addition, the construction methods and construction techniques, such as a device for planting on the outer wall of a building or a waterproof construction and structure of a balcony, are required. These green wall techniques have the potential to be applied by extending them to balcony spaces or double-skin spaces in existing buildings.

One Central Park is a mixed-use facility built in Sydney, Australia. A green wall was installed on the outer wall of the building, where hydroponic cultivation occurs. Since each plant is watered without soil through an irrigation system, it does not impose any structural burden [79]. The building has a circulation system for water resources, so rainwater, underground water, and sewage are utilized and supplied to the green wall plants [79].

4.2. Smart Farm Architecture Planning and Design Strategy in Urban Agriculture

Applying smart farms in urban areas can be divided into methods of constructing new buildings and adding smart farm functions to existing buildings (Figure 3, Table 2). In the case of building a smart farm in an urban area, reference can be made to instances where the entire building is used as a farm (C1, C5) and where a farm is built in connection with a sales facility (C4) (Figure 3, Table 2). The following additions can be made to buildings to convert them into smart farms: a smart farm in an unused space (C2), installing a greenhouse on the roof of a building (C3, C4), installing spaces to grow plants on an outer wall or balcony of a building (C7) (Figure 3, Table 2). However, it is not easy to apply this in the downtown area when the land area is large, such as C6 (Figure 3, Table 2). As such, although the characteristics of the above seven types can be referred to for smart farm planning and design according to similar situations, it is necessary to think more deeply about the application plan for existing buildings to popularize the supply of urban smart farms.

The 171 cases of smart farms around the world show different aspects depending on their physical characteristics or sociocultural environment. The seven characteristics of smart farms can be classified in terms of city/suburb location, building size, growth space density, application location, mining utilization, and the degree of smart technology introduction. In the cases where the land-use conditions were relaxed, such as in suburban areas, the scale of buildings was large. In urban areas, growing spaces were often installed on unused spaces or rooftops. In the case of the active use of lighting, the exterior of the building or the building to be extended on the roof was finished with glass materials. In the case of not using lighting, it was confirmed that the growth environment was clearly controlled by using environmental control facilities. Depending on the purpose of growth, the growth bed is divided into a single layer or a double layer, and the density is divided as well.

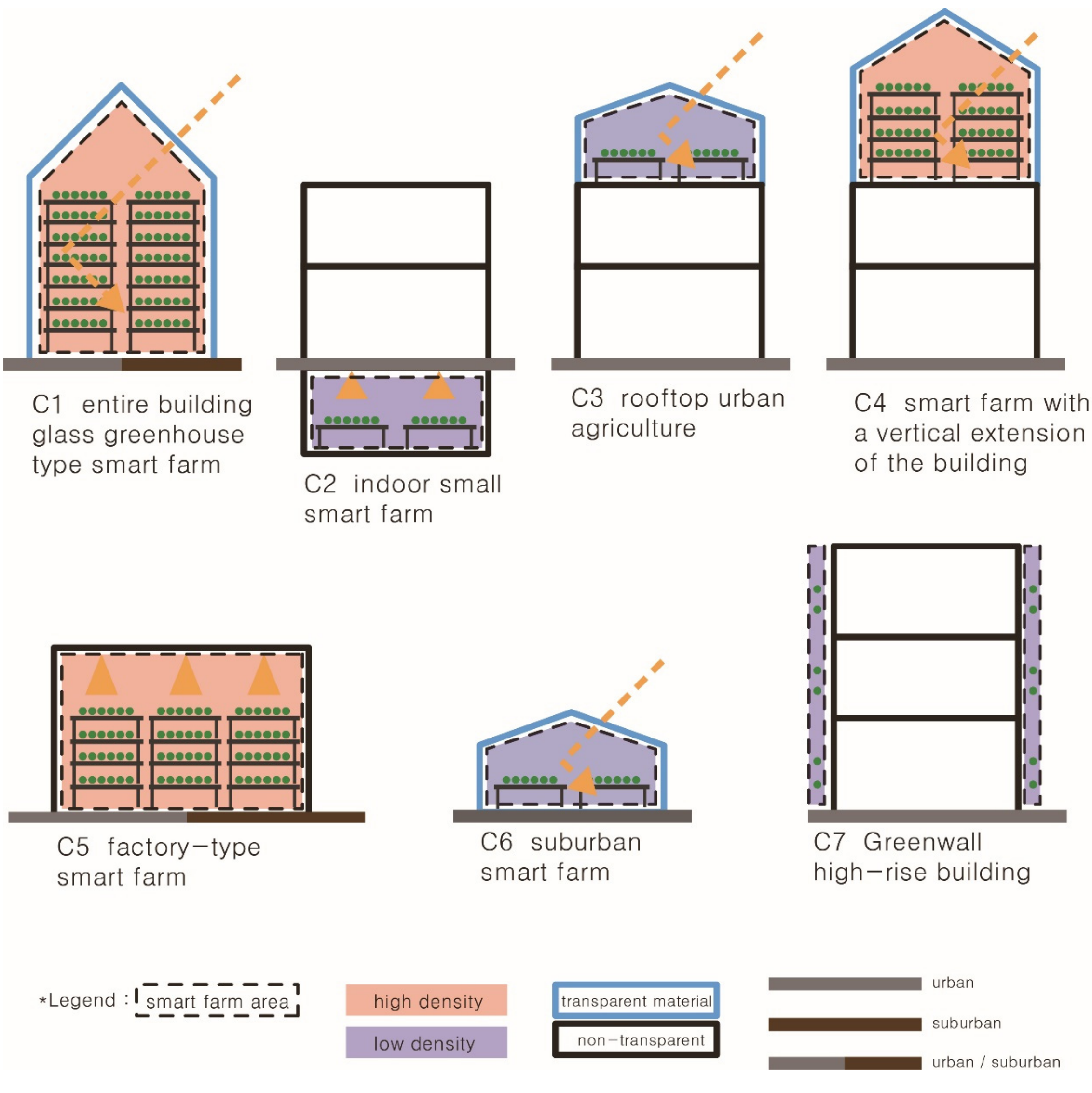

Figure 3. Diagrams of 7 types of architectural characteristics.

Table 2. Characteristics of the 7 types of smart farm.

Type	Urban/Suburban	Building Scale	Growth Density	Application Location	Lighting	Dependence on Smart Technology
C1 entire building glass greenhouse type smart farm	Urban/Suburban	Large	High	ground floor	lighting	High
C2 indoor small smart farm	urban	Small	High	Underground	Non-lighting	High
C3 rooftop urban agriculture	urban	Small	Low	Rooftop	lighting	Low
C4 smart farm with a vertical extension of the building	urban	Large	High	Rooftop	lighting	High
C5 factory-type smart farm	Urban/Suburban	Large	High	ground floor	Non-lighting	High
C6 suburban smart farm	Suburban	Large	Low	ground floor	lighting	normal
C7 Greenwall high-rise building	urban	Large	Low	Exterior Wall	lighting	Low

If there are no legal regulations or problems with the structure or construction during installation, it is possible to install a smart farm in any building, even in an underground or rooftop space. However, regardless of whether it is installed in any building, it is necessary to utilize a greenhouse and program linkage by seeking relationships among building users. Smart farms that link necessary spaces, such as schools (students and teachers: education, practice, rest), sales facilities (seller: processing, research, users: sales, rest, experience), and business facilities (employees: rest, leisure, experience) enhance their function. For example, in the Republic of Korea, the construction type of high-rise apartment houses accounts for more than half of all dwellings; common facilities, landscaping facilities, some spaces in underground parking lots, and rooftop spaces in residential complexes can be installed with smart farms. As in the case of Jardins perchés de Tours, hobbies and leisure life among local residents can be supported, the community can be improved through local activities, and the crops produced can be consumed or sold by residents within the complex to be used for operating expenses. In addition, using unused spaces, such as basements as indoor smart farms, can increase space utilization, and crime anxiety can be reduced. The rooftop space is often closed for safety reasons, but it can also be used as a common relaxation space for residents of the complex.

Rooftop greenhouse-type smart farms are often installed and operated independently. It will depend on the use and conditions of the existing building, but it is desirable to consider circulation, space, and energy linkage. If there is a shared space, such as an atrium or hall in the building, it is desirable to remove part of the roof slab. This is because if the traffic lines are connected, it will be easier to link the spaces between the existing building and the greenhouse.

The electrical wiring between the building and the greenhouse can also be considered. At the same time that light is introduced into the room, polluted air in the building can be circulated through temperature difference ventilation, and a plan can be prepared to introduce oxygen emitted by plants through photosynthesis into the indoor space of the building. The waste heat discharged from the machine room of the building can be used as an energy source for growing plants in the greenhouse by collecting rainwater for plant growth or using it as multi-purpose water within the building. This will minimize the energy used in the greenhouse and further reduce the heating and cooling load of the building.

Figure 4 shows an example of a smart farm installed on the basement, ground floor, and building rooftops. The smart farm is vertically extended on the roof of the building, and an indoor basement is installed on the ground floor and the balcony. Although glass materials with high energy performance and improved airtightness are used, insulation can be used in specific directions to prevent cold winter winds and further improve energy performance. The rooftop greenhouse is spatially linked to the existing building, and energy circulation is carried out throughout the building. The air introduced into the double outer skin of the building is naturally ventilated through the indoor atrium. Rainwater is collected from the rooftop greenhouse, used for humidity control, and stored in a water tank in the building. Solar radiation flows into the rooftop greenhouse and uses rainwater to store heat or generate electricity with Building Integrated Photovoltaic (BIPV). The carbon dioxide and waste heat generated by air conditioners and heaters in the basement can be utilized for crop growth in the rooftop greenhouse.

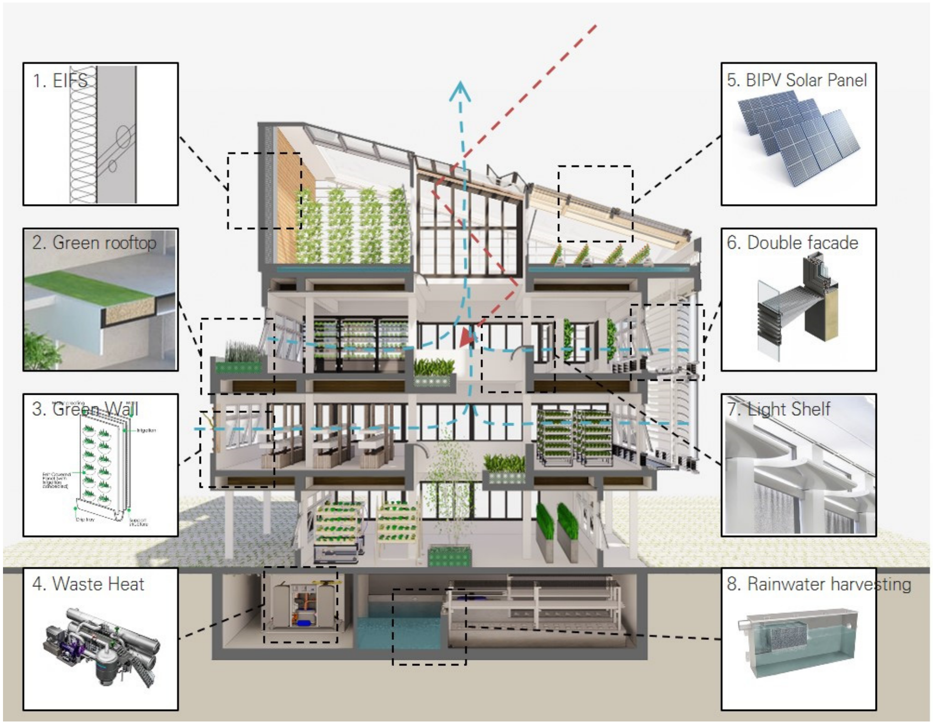

Figure 4. Smart farm application plan for buildings.

5. Conclusions

The urban smart farm concept has emerged as a solution to the problem of climate change, food shortages, and environmental pollution. However, it is a relatively new concept that needs more architectural planning and design information. By collecting cases of smart farms worldwide and analyzing their types, this study tried to materialize the architectural plan and design concept of smart farms.

The characteristics were examined through representative cases of seven types derived through analysis. The seven characteristics of smart farms can be classified in terms of city/suburb location, building size, growth space density, application location, mining utilization, and degree of smart technology introduction. Although seven types of characteristics can be referred to for planning and designing smart farms, it is necessary to consider how to apply them to existing buildings to spread in urban areas. To this end, we presented three points of consideration: the linkage between programs and greenhouses according to building use, the linkage between buildings and greenhouses and space and circulation, and the linkage of energy between greenhouses and buildings.

This study is meaningful in that it embodied the concept of smart farm planning and design through case analysis. In future studies, it is necessary to present a more specific design proposal when smart farms are applied to buildings in urban areas.

Author Contributions: Conceptualization and methodology, D.S. and N.B. and E.L.; software and formal analysis and data curation, Y.L. and J.L.; writing—original draft preparation, D.S.; writing—review and editing, N.B.; visualization and supervision, D.S.; funding acquisition, E.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (20212020800050).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors wish to express their gratitude to the anonymous reviewers for the comments and suggestions provided, which have been very helpful in improving the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The variables that contribute to forming U-matrix clusters are shown in the profile graph [71], where the characteristics of each type can be understood. If the graph is located on the right side of the center, it indicates that the variable belongs to the corresponding cluster. Conversely, if it is located on the left side, it indicates that the variable does not belong to the cluster. This graph shows the relationship between the occupied area of the U-Matrix and the Plane Map. A variable that appears in the graph has as high a frequency of occurrence (occupied area) as a variable that contributes to clustering. This is because the variable can occupy other clusters. For the contribution of a cluster, it is necessary to check the tendency of a specific variable to appear only in a specific cluster. In the graph below(Figures A1–A7), the variables marked with red borders represent the variables that contributed significantly to the formation of clusters.

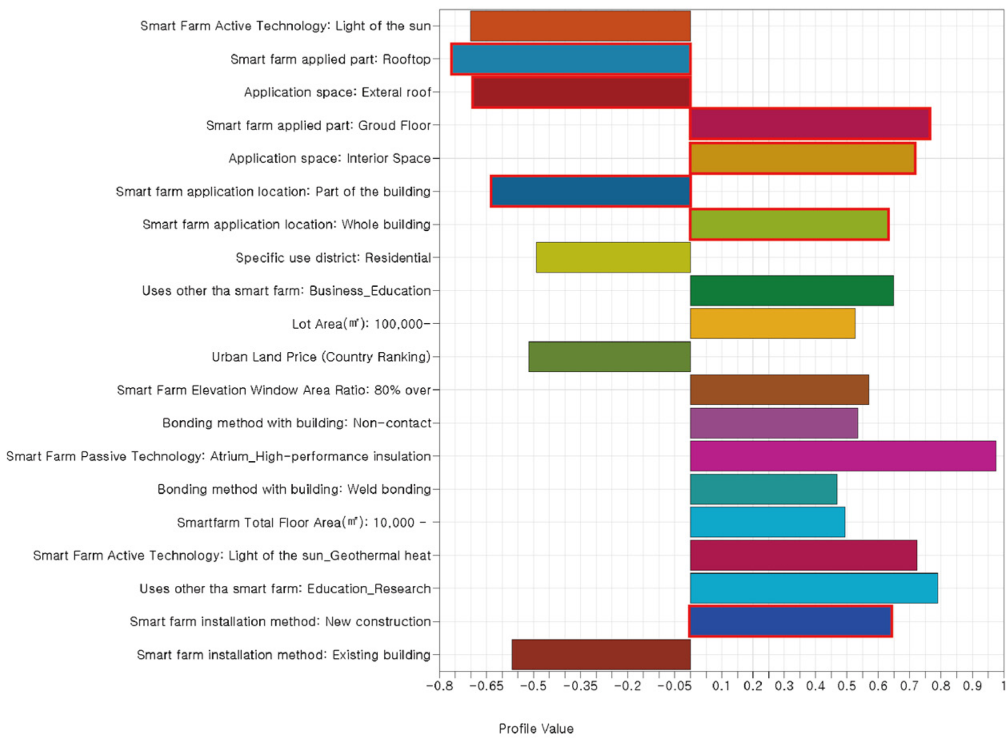

Figure A1. C1.

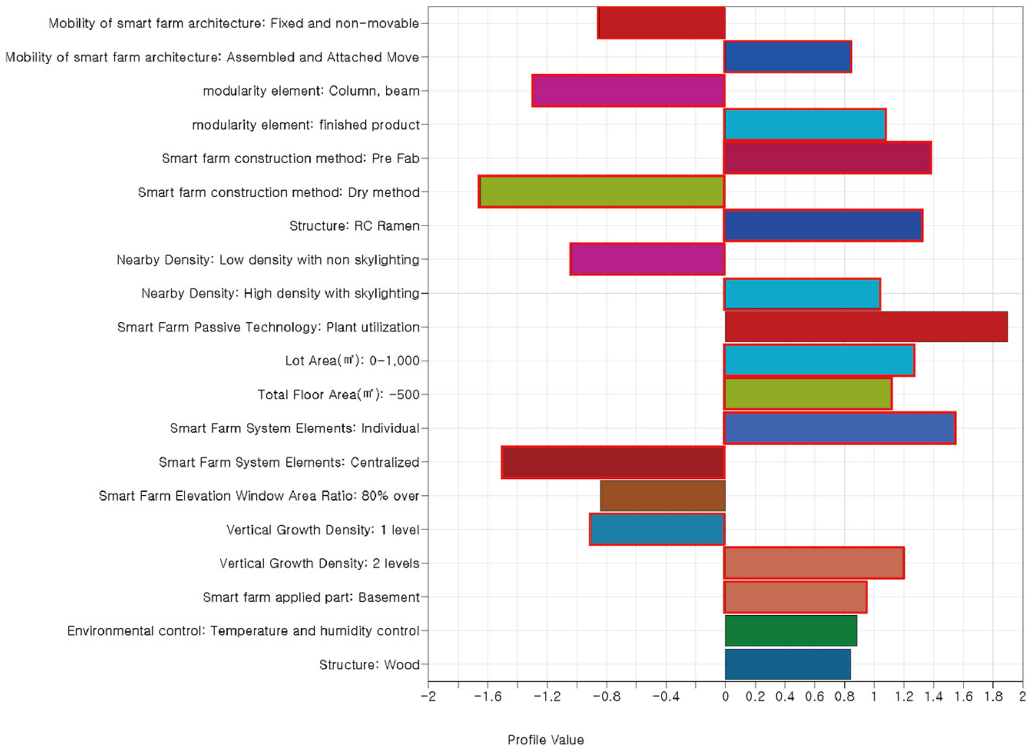

Figure A2. C2.

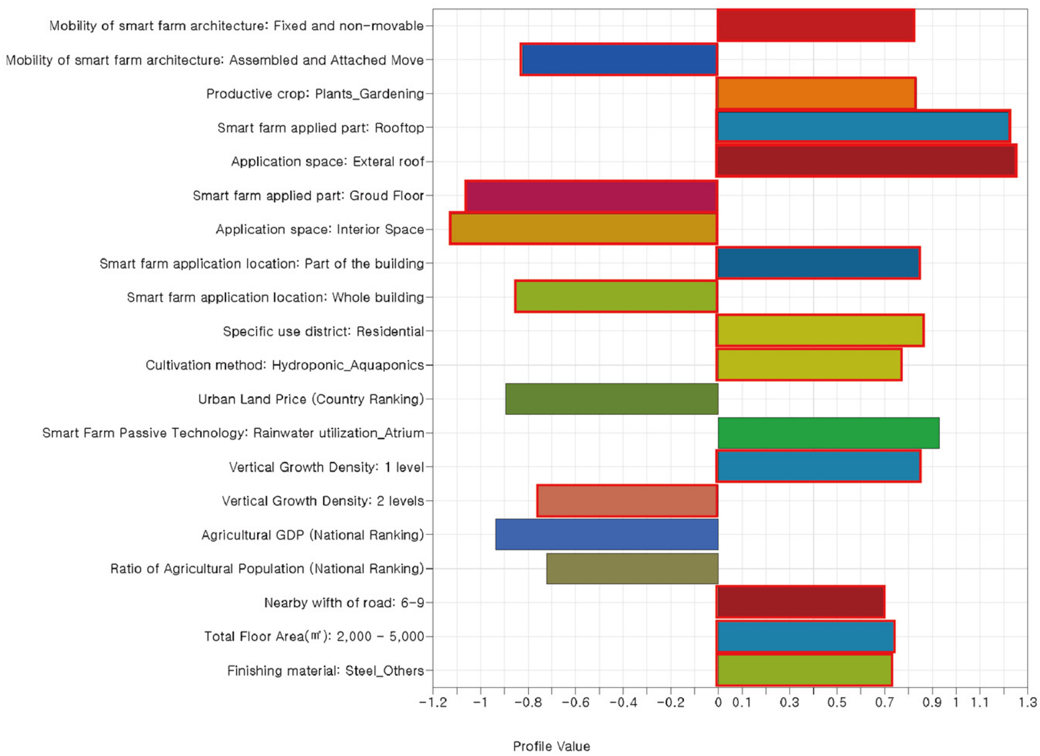

Figure A3. C3.

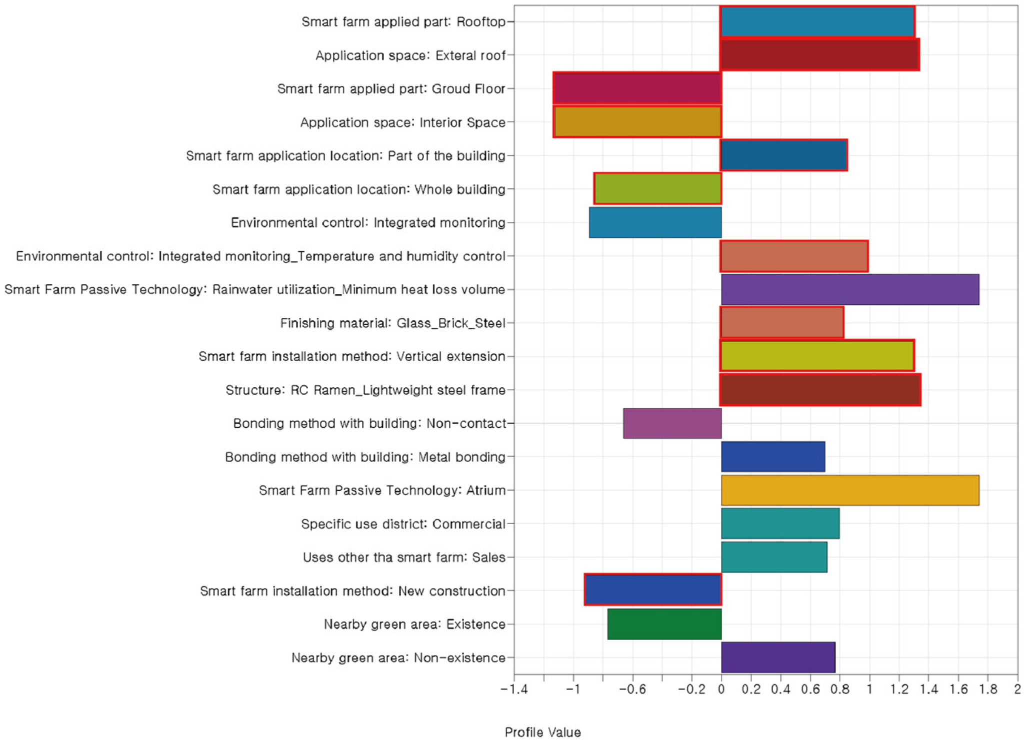

Figure A4. C4.

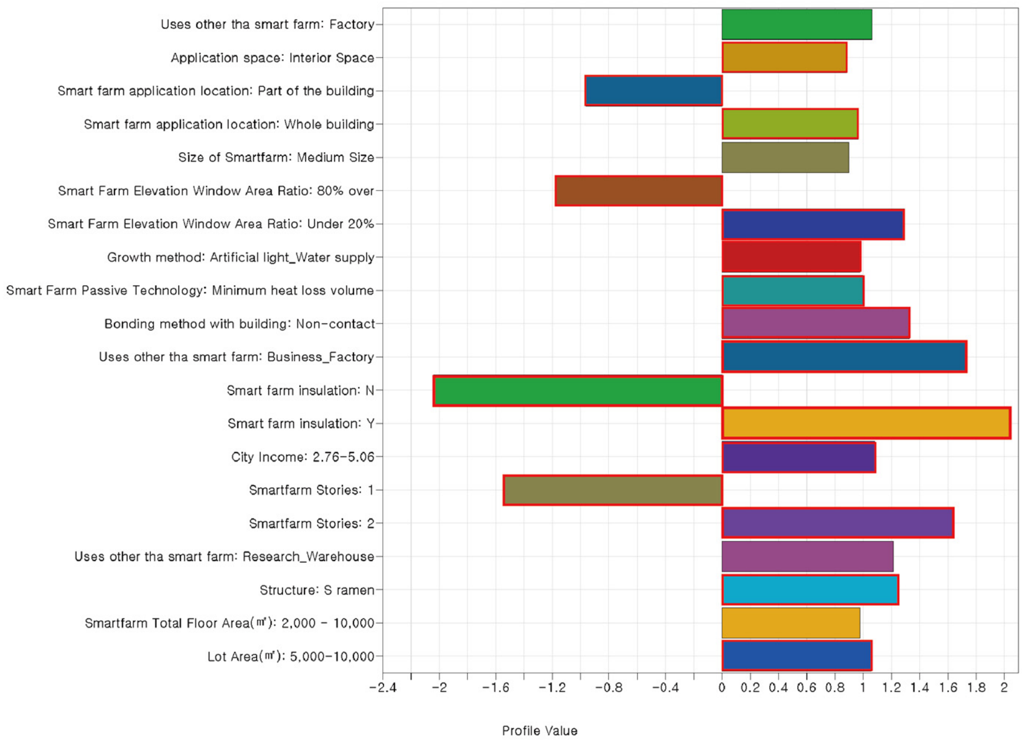

Figure A5. C5.

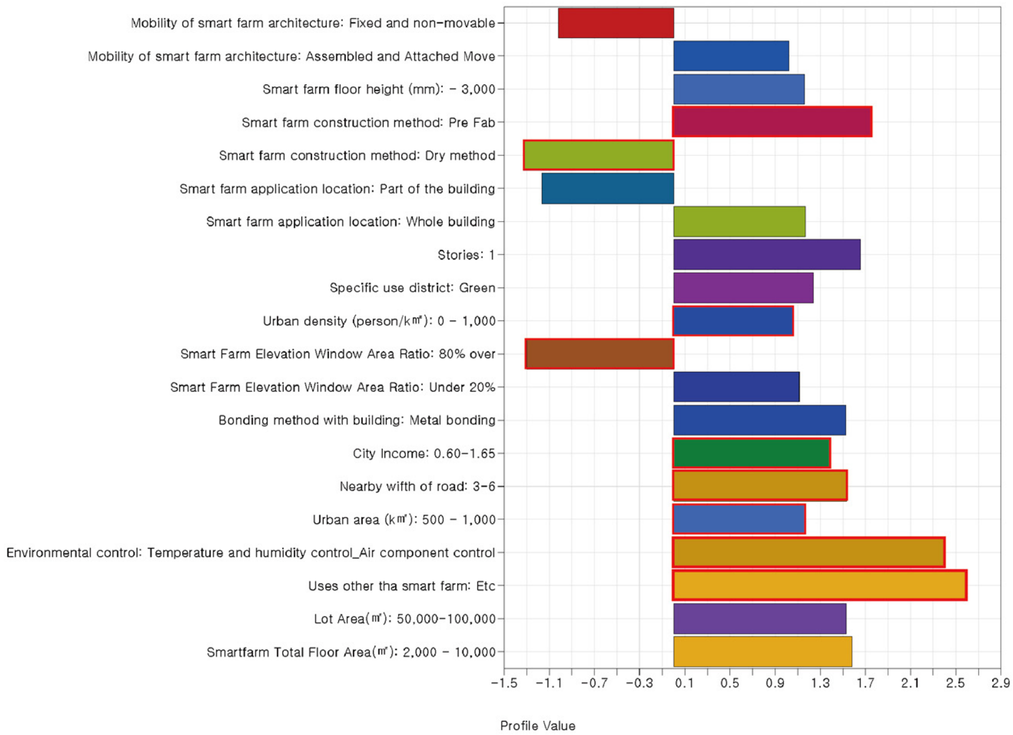

Figure A6. C6.

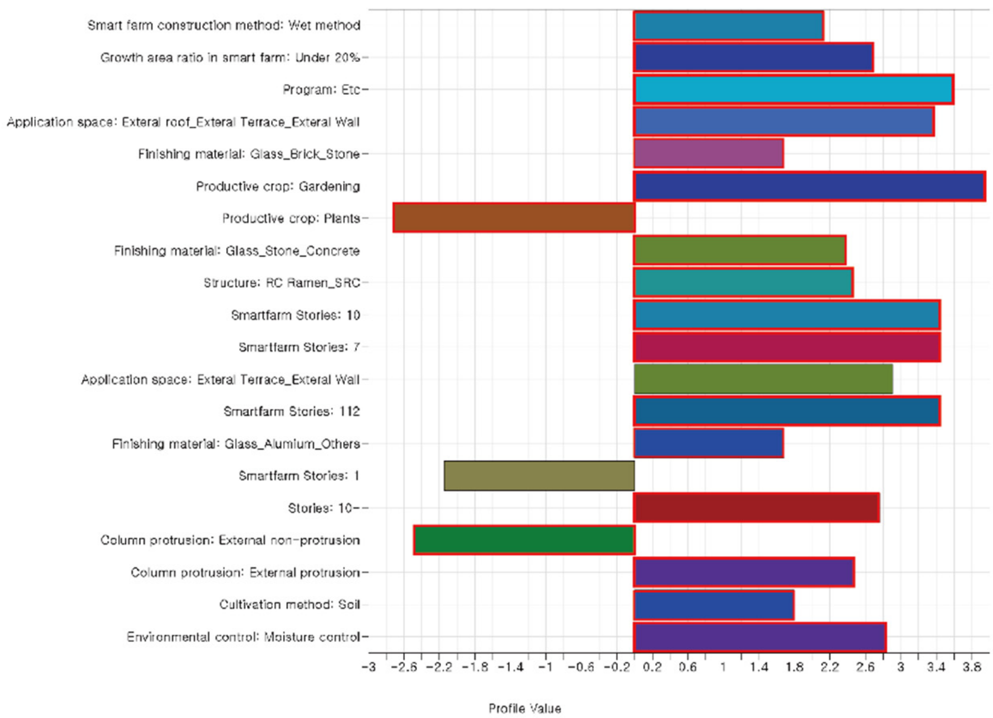

Figure A7. C7.

Appendix B

The Plane Map is a map that visually displays all variables' characteristics for the entire U-Matrix cluster [71]. Therefore, it has the advantage of being able to grasp the relationship or contribution of each variable to the entire cluster at a glance. For example, the figure below shows the Plane Map for 290.

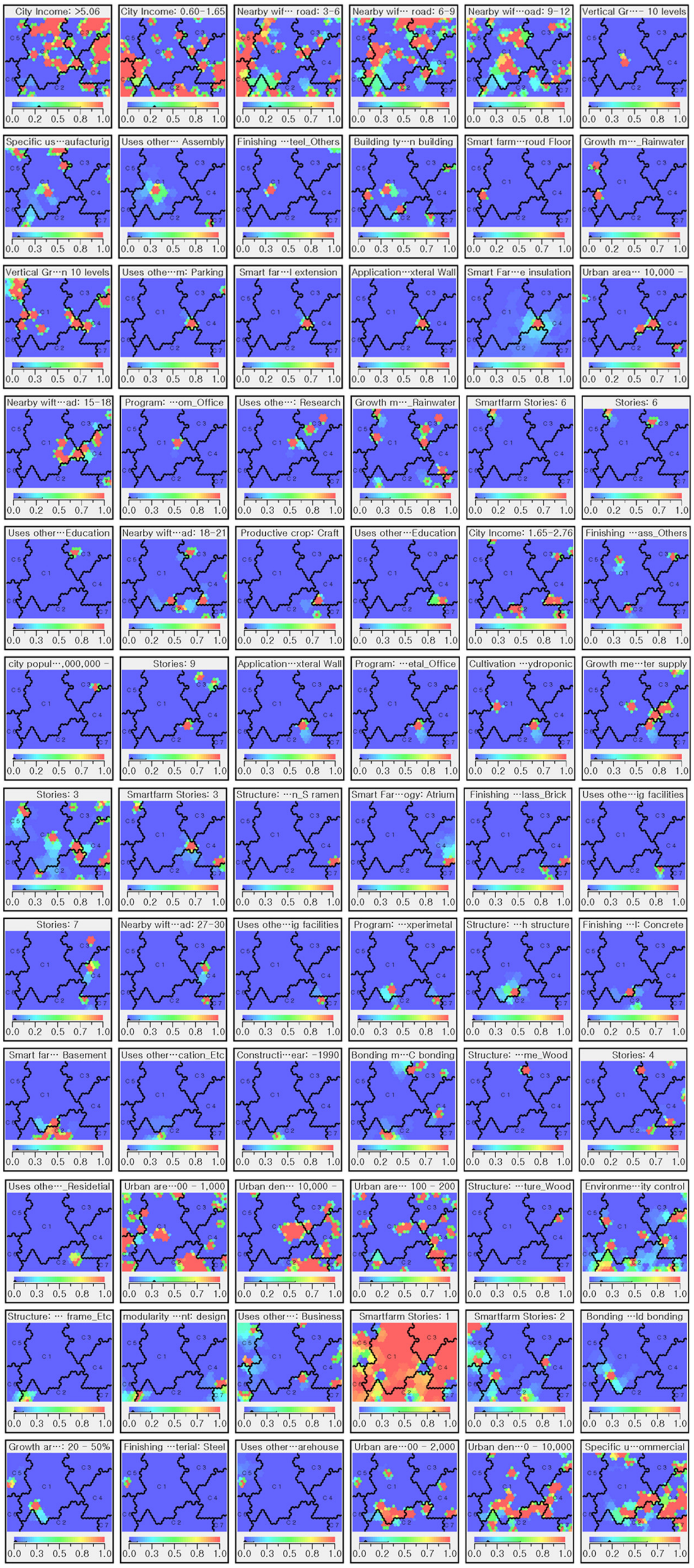

Figure A8. *Cont.*

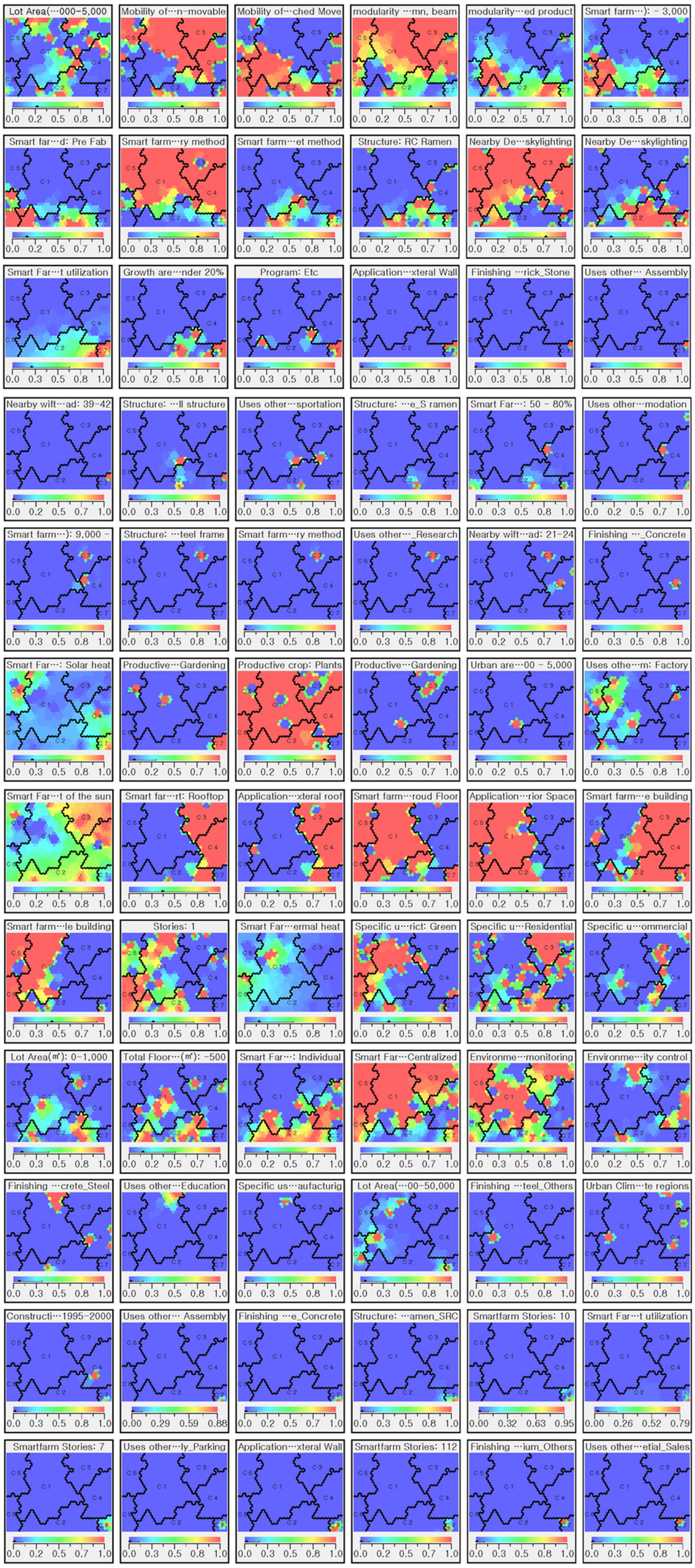

Figure A8. *Cont.*

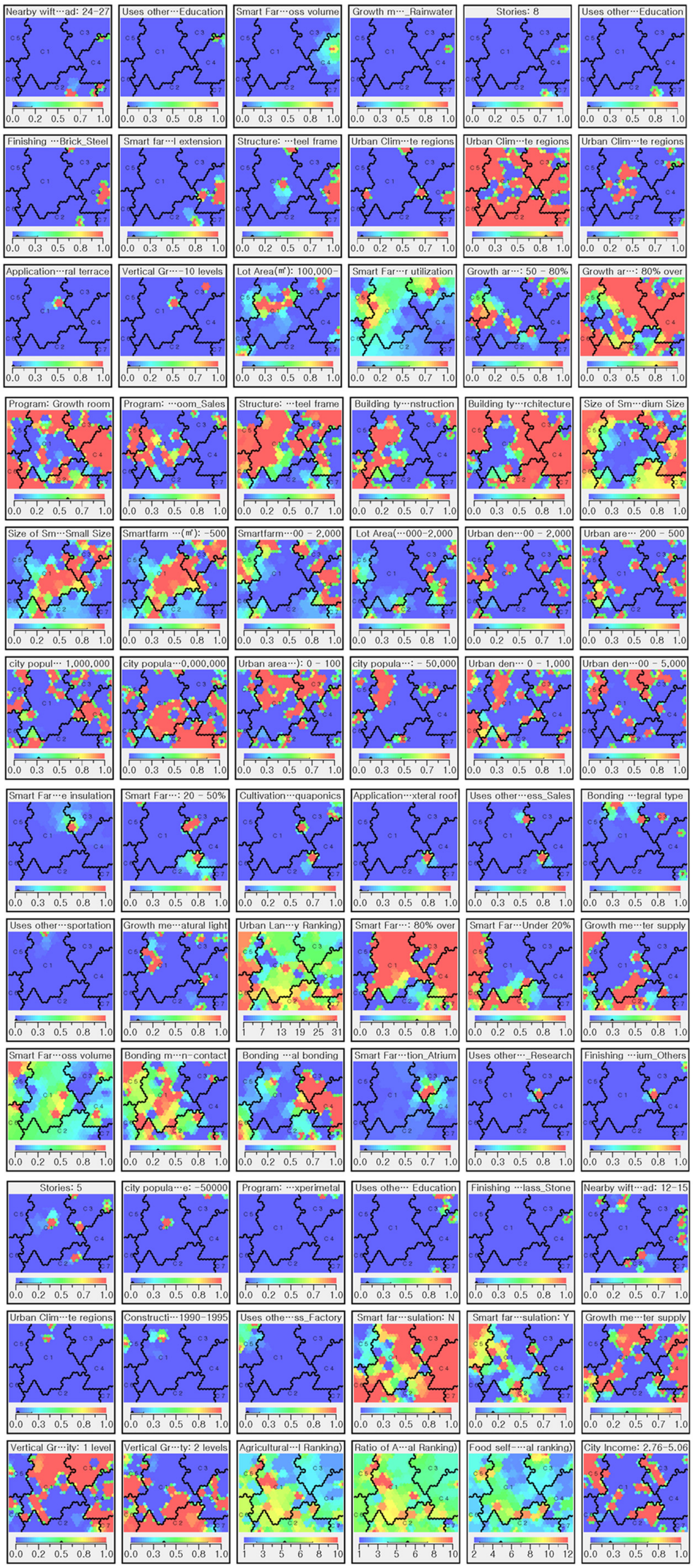

Figure A8. *Cont.*

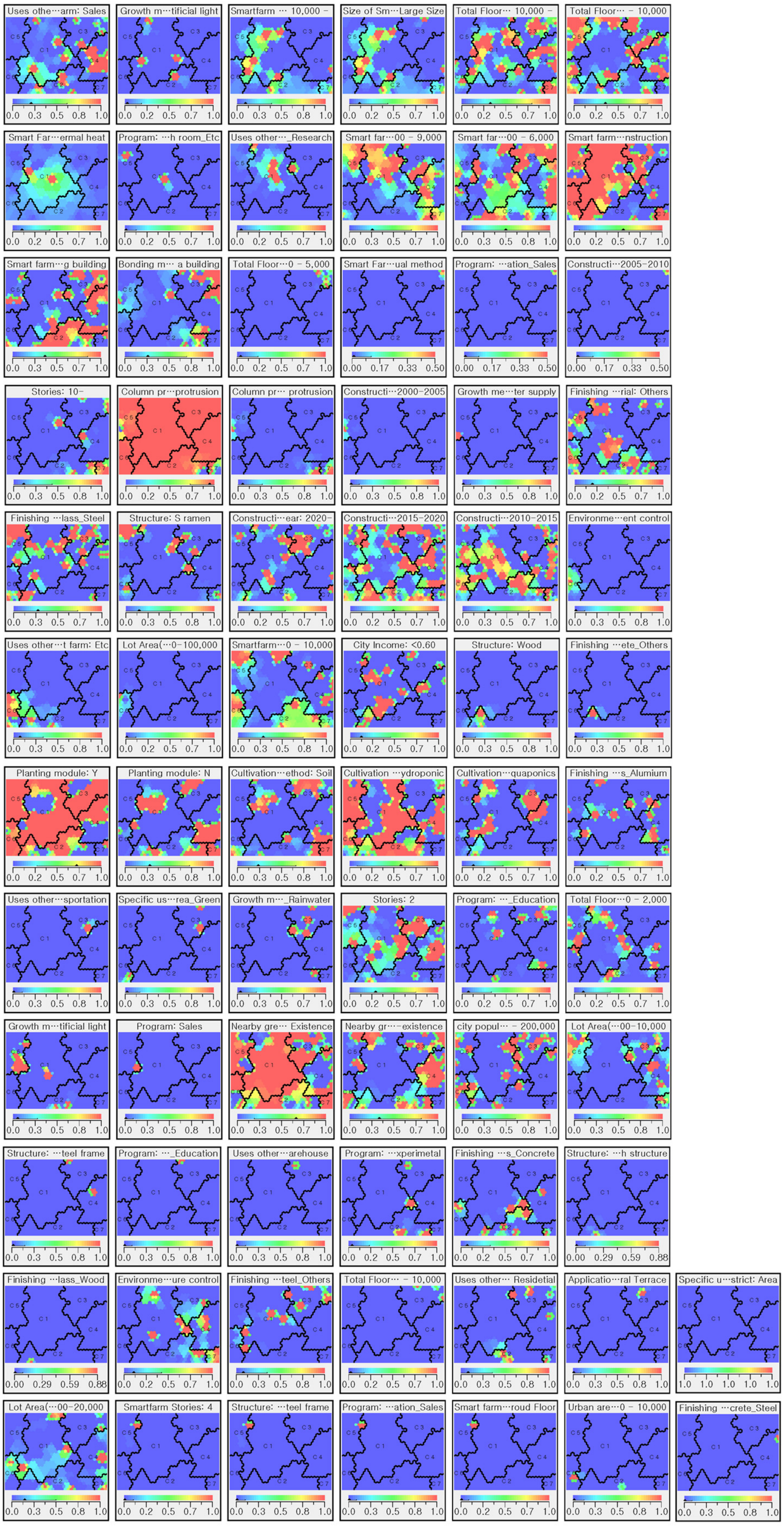

Figure A8. Plane Map for All Variables.

References

1. United Nations (UN). World Population Prospects 2022. Available online: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf (accessed on 3 August 2022).
2. United Nations (UN). World Urbanization Prospects 2018. Available online: https://population.un.org/wup/Publications/ (accessed on 3 August 2022).
3. Centre for Liveable Cities. *New Lenses on Future Cities: A New Lens Scenarios Supplement*; Shell Scenarios: Singapore, 2014.
4. Hamilton, C.; Turton, H. Determinants of emissions growth in OECD countries. *Energy Policy* **2002**, *30*, 63–71. [CrossRef]
5. Shi, A. The impact of population pressure on global carbon dioxide emissions, 1975–1996: Evidence from pooled cross-country data. *Ecol. Econ.* **2003**, *44*, 29–42. [CrossRef]
6. Parikh, J.; Shukla, V. Urbanization, energy use and greenhouse effects in economic development. *Glob. Environ. Change* **1995**, *5*, 87–103. [CrossRef]
7. Healy, R.G.; Rosenberg, J.S. *Land Use and the States*; Routledge: New York, NY, USA, 2013.
8. Despommier, D. *Encyclopedia of Food and Agricultural Ethics (Vertical Farms in Horticulture)*; Springer: Dordrecht, The Netherlands, 2014.
9. Despommier, D. Farming up the city: The rise of urban vertical farms. *Trends Biotechnol.* **2013**, *31*, 388–389. [CrossRef] [PubMed]
10. Despommier, D. *The Vertical Farm: Feeding the World in the 21st Century*; MacMillan: Basingstoke, UK, 2010.
11. Muller, A.; Ferré, M.; Engel, S.; Gattinger, A.; Holzkämper, A.; Huber, R.; Müller, M.; Six, J. Can soil-less crop production be a sustainable option for soil conservation and future agriculture? *Land Use Policy* **2017**, *69*, 102–105. [CrossRef]
12. OECD Policy Responses to Coronavirus (COVID-19), COVID-19 and the Food and Agriculture Sector: Issues and Policy Responses. Available online: https://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-food-and-agriculture-sector-issues-and-policy-responses-a23f764b (accessed on 3 August 2022).
13. Langemeyer, J.; Madrid-Lopez, C.; Mendoza Beltran, A.; Villalba Mendez, G. Urban agriculture—A necessary pathway towards urban resilience and global sustainability? *Landsc. Urban Plan.* **2021**, *210*, 104055. [CrossRef]
14. Pulighe, G.; Lupia, F. Food First: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. *Sustainability* **2020**, *12*, 5012. [CrossRef]
15. Zaręba, A.; Krzemińska, A.; Kozik, R. Urban vertical farming as an example of nature-based solutions supporting a healthy society living in the urban environment. *Resources* **2021**, *10*, 109. [CrossRef]
16. Whittinghill, L.J.; Rowe, D.B. The role of green roof technology in urban agriculture. *Renew. Agric. Food Syst.* **2012**, *27*, 314–322. [CrossRef]
17. Ackerman, K.; Conrad, M.; Culligan, P.; Plunz, R.; Sutto, M.P.; Whittinghill, L. Sustainable food systems for future cities: The potential of urban agriculture. *Econ. Soc. Rev.* **2014**, *45*, 189–206.
18. Lovell, S.T. Multifunctional urban agriculture for sustainable land use planning in the United States. *Sustainability* **2010**, *2*, 2499–2522. [CrossRef]
19. UNDP. *Urban agriculture. Food, Jobs and Sustainable Cities*; Publication Series for Habitat II; United Nations Development Program: New York, NY, USA, 1996.
20. Delgado, J.A.; Dillon, M.A.; Sparks, R.T.; Essah, S.Y.C. A decade of advances in cover crops: Cover crops with limited irrigation can increase yields, crop quality, and nutrient and water use efficiencies while protecting the environment. *J. Soil Water Conserv.* **2007**, *62*, 110A–117A.
21. De Bon, H.; Parrot, L.; Moustier, P. Sustainable urban agriculture in developing countries. A review. *Agron. Sustain. Dev.* **2010**, *30*, 21–32. [CrossRef]
22. Lattuca, A.; Terrile, R.; Bracalenti, L.; Lagorio, L.; Ramos, G.; Moreira, F. Building food secure neighborhoods in Rosario. *Urban Agric. Mag.* **2005**, *15*, 23–24.
23. Westphal, L.M. Social aspects of urban forestry. Urban greening and social benefits: A study of empowerment outcomes. *J. Arboric.* **2003**, *29*, 137–147.
24. United Nations (UN). Climate Action. Available online: https://www.un.org/en/climatechange/what-is-climate-change (accessed on 3 August 2022).
25. World Meteorological Organization (WMO). The Role of the Ocean in a Changing Climate. Available online: https://public.wmo.int/en/resources/bulletin/Ocean_Climate_Nexus/The_Role_Ocean (accessed on 3 August 2022).
26. United Nations (UN). Climate Change, the Paris Agreement. Available online: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed on 3 August 2022).
27. United Nations Environment Programme (UNEP). Emissions Gap Report 2021: The Heat Is on—A World of Climate Promises Not yet Delivered. Available online: https://wedocs.unep.org/bitstream/handle/20.500.11822/36990/EGR21.pdf (accessed on 3 August 2022).
28. A Global Screening Tool by Climate Central. Available online: https://coastal.climatecentral.org/ (accessed on 3 August 2022).
29. Food and Agriculture Organization (FAO), Chapter 15. Good agricultural practices for greenhouse vegetable crops. In *Principles for Mediterranean Climate Areas*; Food and Agriculture Organization: Roma, Italy, 2013.
30. World Food Programme. War in Ukraine Drives Global Food Crisis. Available online: https://www.wfp.org/publications/war-ukraine-drives-global-food-crisis (accessed on 3 August 2022).

31. The New York Times, Ukraine War Threatens to Cause a Global Food Crisis. Available online: https://www.nytimes.com/2022/03/20/world/americas/ukraine-war-global-food-crisis.html (accessed on 3 August 2022).
32. Bailey, G. *Vertical Farming*; Kessinger Publishing, LLC: Whitefish, MT, USA, 1915.
33. Al-Kodmany, K. The vertical Farm: A review of developments and implications for the vertical city. *Buildings* **2018**, *8*, 24. [CrossRef]
34. Harris, D. *Hydroponics: A Practical Guide for the Soilless Grower*, 2nd ed.; New Holland Publishing: London, UK, 1992.
35. Anand, P.; Singh, Y.; Selwal, A.; Alazab, M.; Tanwar, S.; Kumar, N. IoT vulnerability assessment for sustainable computing: Threats, current solutions, and open challenges. *IEEE Access* **2020**, *8*, 168825–168853. [CrossRef]
36. Eli-Chukwu, N.C. Applications of artificial intelligence in agriculture: A review. *Eng. Technol. Appl. Sci. Res.* **2019**, *9*, 4377–4383. [CrossRef]
37. Conteratto, C.; do Carmo Martinelli, G.; de Oliveira, L. Food security, smart agriculture and sustainability: The state of the art in the scientific field. *Risus* **2020**, *11*, 33–43. [CrossRef]
38. Ruiz-Real, J.L.; Uribe-Toril, J.; Torres Arriaza, J.A.; de Pablo Valenciano, J. A look at the past, present and future research trends of artificial intelligence in agriculture. *Agronomy* **2020**, *10*, 1839. [CrossRef]
39. Schroeder, K.; Kamel, A.; Sticklen, J.; Ward, R.; Ritchie, J.; Schulthess, U.; Rafea, A.; Salah, A. Guiding object-oriented design via the knowledge level architecture: The irrigated wheat testbed. *Math. Comput. Modell.* **1994**, *20*, 1–16. [CrossRef]
40. Nugent, R. The impact of urban agriculture on the household and local economies. In *Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda: A Reader on Urban Agriculture*; Bakker, N., Dubbeling, M., Gündel, S., Sabel-Koschella, U., De Zeeuw, H., Eds.; DSE/ETC: Feldafing, Germany, 2000; pp. 67–97.
41. Vagneron, I. Economic appraisal of profitability and sustainability of peri-urban agriculture in Bangkok. *Ecol. Econ.* **2007**, *61*, 516–529. [CrossRef]
42. Mukherji, N.; Morales, A. *Zoning for Urban Agriculture. Zoning Practice 3*; American Planning Association: Chicago, IL, USA, 2010.
43. Akbari, H. Shade trees reduce building energy use and CO2 emissions from power plants. *Environ. Pollut.* **2002**, *116* (Suppl. 1), S119–S126. [CrossRef] [PubMed]
44. Intergovernmental Panel on Climate Change (IPCC). *Synthesis Report; Summary for Policymakers. Climate Change*; IPCC: Geneva, Switzerland, 2007.
45. Fioretti, R.; Palla, A.; Lanza, L.G.; Principi, P. Green roof energy and water related performance in the Mediterranean climate. *Build. Environ.* **2010**, *45*, 1890–1904. [CrossRef]
46. Suszanowicz, D.; Ratuszny, P.; Wróbel, R. The potential of roofs in city centers to be used for photovoltaic micro-installations. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *564*, 012128. [CrossRef]
47. Ascione, F.; Bianco, N.; de' Rossi, F.; Turni, G.; Vanoli, G.P. Green roofs in European climates. Are there effective solutions for the energy savings in air-conditioning? *Appl. Energy* **2013**, *104*, 845–859. [CrossRef]
48. Castleton, H.F.; Stovin, V.; Beck, S.B.M.; Davison, J.B. Green roofs; building energy savings and the potential for retrofit. *Energy Build.* **2010**, *42*, 1582–1591. [CrossRef]
49. Theodosiou, T.G. Summer period analysis of the performance of a planted roof as a passive cooling technique. *Energy Build.* **2003**, *35*, 909–917. [CrossRef]
50. Katz, R.; Bradley, J. *The Metropolitan Revolution. How Cities and Metropolitan Areas Are Fixing Broken Politics and Fragile Economy*; The Brookings Institution Press: Washington, DC, USA, 2013.
51. Idoje, G.; Dagiuklas, T.; Iqbal, M. Survey for smart farming technologies: Challenges and issues. *Comput. Electr. Eng.* **2021**, *92*, 107104. [CrossRef]
52. Huang, A.; Chang, F.-J. Prospects for rooftop farming system dynamics: An action to stimulate water-energy-food nexus synergies toward green cities of tomorrow. *Sustainability* **2021**, *13*, 9042. [CrossRef]
53. Hardman, M.; Clark, A.; Sherriff, G. Mainstreaming urban agriculture: Opportunities and barriers to upscaling city farming. *Agronomy* **2022**, *12*, 601. [CrossRef]
54. Ivascu, L.; Frank Ahimaz, D.; Arulanandam, B.V.; Tirian, G.-O. The perception and degree of adoption by urbanites towards urban farming. *Sustainability* **2021**, *13*, 12151. [CrossRef]
55. Grebitus, C.; Chenarides, L.; Muenich, R.; Mahalov, A. Consumers' perception of urban farming—An exploratory study. *Front. Sustain. Food Syst.* **2020**, *4*, 79. [CrossRef]
56. Martellozzo, F.; Landry, J.; Plouffe, D.; Seufert, V.; Rowhani, P.; Ramankutty, N. Urban agriculture: A global analysis of the space constraint to meet urban vegetable demand. *Environ. Res. Lett.* **2014**, *9*, 6. [CrossRef]
57. Fallmann, J.; Emeis, S. How to bring urban and global climate studies together with urban planning and architecture? *Dev. Built Environ.* **2020**, *4*, 100023. [CrossRef]
58. Krikser, T.; Piorr, A.; Berges, R.; Opitz, I. Urban agriculture oriented towards self-supply, social and commercial purpose: A typology. *Land* **2016**, *5*, 28. [CrossRef]
59. National Law Information Center. Act on Development and Support of Urban Agriculture. Available online: https://www.law.go.kr/LSW/eng/engLsSc.do?y=0&x=0&menuId=1&query=urban+agriculture#liBgcolor0 (accessed on 3 August 2022).
60. Oh, J.; Kim, S. Enhancing urban agriculture through participants' satisfaction: The case of Seoul, Korea. *Land Use Policy* **2017**, *69*, 123–133. [CrossRef]

61. Kohonen, T. Essentials of the self-organizing map. *Neural Netw.* **2013**, *37*, 52–65. [CrossRef]
62. Kohonen, T. Self-organized formation of topologically correct feature maps. *Biol. Cybern.* **1982**, *43*, 59–69. [CrossRef]
63. Kohonen, T. *Self-Organizing Maps*; Springer Science and Business Media: Berlin, Germany, 2012; Volume 30.
64. Kohonen, T. The self-organizing map. *Proc. IEEE* **1990**, *78*, 1464–1480. [CrossRef]
65. Shon, D. Analysis of Traditional Urban Landscape Composition Using Data Mining: Focusing on Hanok Facade and Street Elements in Bukchon. Ph.D. Thesis, Seoul National University, Seoul, Republic of Korea, 2018.
66. Liu, Y.; Weisberg, R.H.; Mooers, C.N.K. Performance evaluation of the self-organizing map for feature extraction. *J. Geophys. Res.* **2006**, *111*. [CrossRef]
67. Kaski, S.; Kangas, J.; Kohonen, T. Bibliography of self-organizing map (SOM) [Papers; pp. 1981–1997]. *Neural Comput. Surv.* **1998**, *1*, 102–350.
68. Park, J.; Kim, S. A study on the space usage by the new hanok plan composition—Focused on the new hanok in Jeollanam-do Province. *J. Korean Hous. Assoc.* **2012**, *23*, 59–67. [CrossRef]
69. Shon, D.; Choi, J.; Jeong, K. Analysis of residence type and characteristics of local resident in Korean apartment in Hanoi, Vietnam. *J. Archit. Inst. Korea Plan. Des.* **2017**, *33*, 45–52. [CrossRef]
70. Shon, D.; Lee, J. Category derivation of 'hanok architectural style' through typology analysis. *J. Archit. Inst. Korea* **2020**, *36*, 15–24. [CrossRef]
71. VIscovery SOMine. Available online: https://www.viscovery.net/ (accessed on 3 August 2022).
72. Greens, G. Available online: https://www.gothamgreens.com/ (accessed on 7 November 2022).
73. Vertical Harvest Jackson. Available online: https://verticalharvestfarms.com/ (accessed on 7 November 2022).
74. Farmaco. Available online: http://www.farm8.co.kr/16539 (accessed on 7 November 2022).
75. Perchés, L.J. Un Projet Innovant à Tours. Available online: https://les-jardins-perches.fr/ (accessed on 7 November 2022).
76. Verticrop. Available online: https://grow.verticrop.com/vertical-farming/ (accessed on 7 November 2022).
77. Plant, S.K. Available online: https://www.meti.go.jp/english/policy/sme_chiiki/plantfactory/exam/spread.html/ (accessed on 7 November 2022).
78. Jinan Local Government. Available online: http://www.jinan.go.kr (accessed on 7 November 2022).
79. Ateliers Jean Nouvel: One Central Park. Available online: http://www.jeannouvel.com/en/projects/one-central-park/ (accessed on 7 November 2022).