



TDK THESIS

AYDANE HAYTAM

2024

UNIVERSITY OF DUNAÚJVÁROS



TDK THESIS

Supervisor:

DR. GYÖRGY ÁGOSTON

COLLEGE PROFESSOR

INSTITUTE OF COMPUTER

ENGINEERING, DEPARTMENT OF

SOFTWARE DEVELOPMENT AND

APPLICATIONS

DR. ANTAL JOÓS

INSTITUTE OF COMPUTER

ENGINEERING, DEPARTMENT OF

MATHEMATICS

ASSOCIATE PROFESSOR

Student:

AYDANE HAYTAM

UNIVERSITY OF DUNAÚJVÁROS

INSTITUTE OF COMPUTER

ENGINEERING, 2024

*Geographic optimization of vertical
farm installation using drone delivery
transport method in Budapest*

Abstract

This essay was done based on a research paper that shares the same topic, that I was part of, where the idea of setting up vertical farms is discussed, in a way that its location and positioning is mathematically optimized along the capital city of Hungary, Budapest. Where my job was to calculate the mathematical results. The aim is to provide a comprehensive coverage of the city where two, three or four sites are established, and compared between this and the current technical conditions and legal situations, keeping in mind that the means of transport that we are considering is the drone delivery, which in the meantime encounter a complicated situation. In this research we have used maps that helped us determine the exact coordinates using google maps, and some images from real Vertical Farms here in Hungary to expand our view based on reality.

I have chosen this project because vertical farming, has gained attention in places like China and Japan, but it's still fairly new and less common in many other parts of the world. I saw this as a great chance to explore into the benefits of vertical farms and show why they're so important to our future. Vertical farms let us grow food year-round in controlled environments, so we're less affected by unpredictable seasons or climate changes. This could be a huge help in supporting the food needs of growing cities where traditional farms might struggle to keep up.

On top of that, vertical farms are a step towards reducing the environmental strain from farming on our planet's natural resources. By bringing food production closer to urban areas, we cut down on transportation emissions and reduce the need for deforestation and large-scale farming, which can harm ecosystems. In this essay, I explore these advantages and highlight why technologies like vertical farming are worth considering and applying if we want to keep up with population growth without compromising our environment.

In conclusion, this research opens exciting possibilities for how vertical farms could evolve in the future. There's so much potential to make these farms even more sustainable by exploring eco-friendly solutions like solar panels or wind power, helping us grow food with minimal environmental impact. We could also look at how AI might play a role in making these farms smarter, imagine crops that get exactly the right amount of light, water, and nutrients, all thanks to technology that learns from real-time data.

Beyond the tech, it's important to think about how this shift could impact people's jobs. As vertical farms grow, they could create new roles in areas like farm management,

tech support, and logistics. Understanding these changes could help ensure these innovations support communities as well as the environment. There's a lot of room for future research to make vertical farming not only a technological success but also an essential thing in our life, too.

Keywords: Vertical farm, cost optimization, drone delivery, Budapest

Table Of Contents

1. Introduction:	1
1.1. The means of transport:	1
1.2. Hungary and Vertical Farming:	2
2. Analysis:	4
3. Evaluation.....	13
4. Further Focus Points.....	16
4.1. Beyond Budapest	16
4.2. Non-Flying Zones	16
4.3. Drones	16
4.4. The Use of Ecological Solutions.....	17
4.5. AI and Vertical Farming:	18
4.6. Reduction of food waste:	19
4.7. Job creation	19
4.8. Summary:.....	20
5. Conclusion.....	Error! Bookmark not defined.
6. Other Points	Error! Bookmark not defined.
7. Acknowledgement:.....	26
8. References:	Error! Bookmark not defined.

1. Introduction

As I mentioned, based on this paper [1], This essay was written. You would ask why even consider the idea of vertical farms, well I am here to tell you that we will going to need them more than we think in the near future, because having a controlled environment of something gives you the ability to firstly control the growth in a specific matter and in accordance to your needs, more than that it gives you the peace of mind and the ability to not worry about the external factors (floods, lack of rain, harsh weather...), plus having this type of environment will require in terms of water approximately 95% less. This essay will discuss the hypothetical scenario, where Budapest will be served by some local vertical farms (abbreviation: VF). The capital was selected because of the high purchase capacity of Its population, as it is considered the center and most developed region in Hungary (the second richest region is situated in western Hungary, encompassing several minor settlements). Keeping this in mind, we want to indicate that currently the cost of vertical farms is relatively high, but not extreme, so the product is limited to those that have a high purchasing power. For example, in 2024 the investment cost for a VF with a production area of 1 square meter is 700-1,000 euros. In 2018 it was 1,500-2,000 euros. The price includes air conditioning, software, shelving, irrigation, machinery, service rooms (preparation and harvesting rooms) and office space, with the additional assumption that the building already exists (brownfield investment, “building in building” concept). Basic calculations can be made using a dedicated website of iFarm (<https://ifarm.fi>). Also running costs are high, because a vertical farm requires a lot of energy [2].

1.1. The means of transport

The use of drone delivery will give us a better edge and the ability to neglect the geographic state during the delivery. In this scenario, the start point is a base that is set up close to the vertical farms, after the harvesting process the weight will be relatively light considering that the drone capacity is higher, will be able to deliver to the destination, but to reduce the transportation costs [3], it is our job to ensure that the best location is chosen which we will achieved through the application of a pure mathematical model. We must note that the drone delivery is not yet legal in Hungary, but it is in some other countries [4], and we hope that in the near future It will be considered and regulated.

1.2. Hungary and Vertical Farming

The history of vertical farming in Hungary is relatively not new, but between the two World Wars, but especially during the Communist period in Hungary (1945-1989), just like in other parts of the world, the first commercial greenhouses appeared mainly for plantlet and high wired crop production. The biggest ones were in the South-Eastern region of Hungary, between Szentes, Kecskemét, Szeged and Orosháza, one example is Árpád-Agrár Ltd. in the city of Szentes. The region was mainly got on the focus of modern horticultural sector after thermal water springs were discovered during the search for oil and natural gas during the 1960s. However, the first closed type plant production facilities with lamps were introduced in research institutes at the Hungarian Academy of Sciences, Agricultural Department in Martonvásár, Fertőd and Szeged, during 1960-80s. The main purpose of these facilities was cereal breeding and basic plant physiology-related research. Martonvásár and Szeged recently upgraded their indoor research infrastructure with an autonomous phenotyping system. One of the first notable vertical farm in Hungary was operated between 2016 and 2018, namely “LivingIsland”, which was introduced as a project scale commercial vertical farm in Budapest by Biopolus Institute (with the partnership of Budapest Waterworks) as a pioneer of Hungarian urban vertical farming for demo pro-duction scale vertical farms.

No description of Hungary would be complete without a description of an old, world-famous lighting company. A larger scale of 150 sqm production area R&D vertical farm was realized at Tungsram Operations Ltd. HQ in Budapest in 2021, after Tungsram Agritech division was established in 2019 (Fig. 1). Tungsram decided to start the vertical farm as a new business unit, because approximately 30% of the installation costs of such a farm is the cost of lighting, and the company has more than 100 years of experience in lighting. The main focus was research and development of vertical farm hardware production, but most importantly horticultural lighting production, and making farm production experiments. The farm was realized with the significant financial support of the Hungarian government, and with the partnership of Biopolus Institute.



Figure 1: Some of Tungstram Agritech products: Growth Cabinet, a mobile vertical farm (left) and special horticultural LED portfolio (right). Source: Tungstram information sheet (Tungstram Agritech, n.d.).

Sadly, Tungstram which was founded in 1896 went into bankruptcy in 2022, due to COVID-19 pandemic (disappearance of customers, collapse of the supply chain), and as side effect of the Russian invasion of Ukraine started in 2022. It was also due to unfavorable governmental support and inappropriate management decisions, and in many cases outdated product portfolio and manufacturing technique. The liquidation process started in 2023 and finishes by the end of 2024. The Agritech business unit survived all difficulties. Its successors are Csillagváros Ltd. and Food Autonomy Ltd. still managed to break into the global elite group in terms of lamp production and research (with Wageningen University & Research – WUR, Living Lab). Csillagváros Ltd. is mainly focusing on vertical farm related research and development programs with focusing on crop growth recipe development and Deep Space related research trials on vertical farms with the help of Orion Space Generation Foundation. Nowadays Food Autonomy Ltd. products are mostly horticultural lamps [5].

2. Analysis

We will consider a maximum of 4 sites, because exceeding this number would exceed the scope of this essay as the mathematical side will be more complicated and advanced.

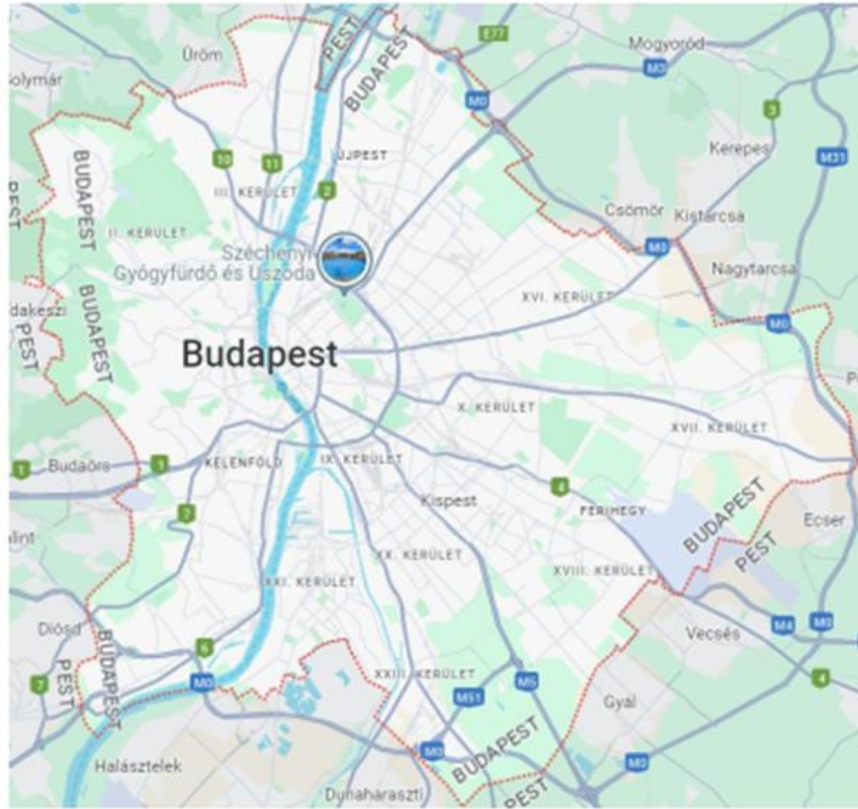


Figure 2: The map of Budapest

The study focuses on the city of Budapest, which, as illustrated in Figure 2, is marked by a red dashed line representing its administrative boundary. However, this boundary is somewhat irregular and unpredictable, which presents challenges for straightforward analysis. To address this and make the application of mathematical techniques for the study more feasible, we decided to expand our analysis to include a slightly larger geographical area. This expanded area encompasses not only Budapest but also a portion of the surrounding suburban and agglomeration zones.

These suburban areas are significant because they contain a considerable portion of the population, highlighting the importance of including them in any comprehensive service or infrastructure planning.

One of the factors we considered when choosing to focus on air transport as the primary mode of service delivery was that this mode renders certain geographical and

infrastructural constraints irrelevant. Specifically, features such as mountains, plains, rivers, or the quality of the road network (whether it consists of highways, main roads, or urban streets) do not significantly impact air transport operations, especially in the case of drone-based services. This flexibility in transport mode allows us to focus solely on the most effective distribution of service coverage areas without being constrained by terrestrial infrastructure or natural barriers.

In this study, each service provider, represented by a vertical farm, also functions as a base for drones. For ease of visualization and analysis, each vertical farm and its corresponding drone base is represented by a circle, which illustrates its service or coverage area. The farm and drone base are located at the center of this circle, meaning the coverage area radiates outward from that central point. This circular representation simplifies the analysis by allowing us to use geometric and mathematical models to determine the extent of the coverage provided by each farm.

For the sake of consistency and simplicity, it is assumed that all the sites (or vertical farms) have identical capacities. This assumption implies that each farm can serve an equal number of people or cover the same area within the city, regardless of its location. As a result, each service or coverage area is modelled as a circle of the same size, all with the same radius. These simplified conditions allow for a more straightforward approach to the optimization process, where the focus is on how best to distribute the farms to achieve maximum coverage.

Once these boundary conditions and assumptions have been established, we can proceed with the mathematical optimization process. The optimization seeks to determine the best locations for placing the farms and drone bases in order to maximize the coverage of the city and its surrounding areas. Specifically, four distinct scenarios are being considered: the placement of 1, 2, 3, or 4 vertical farm sites. Each scenario presents a different level of service capacity and distribution, and the objective in each case is to ensure that all areas within the designated region are fully covered by at least one farm.

In each scenario, the key goal is to provide comprehensive coverage of Budapest, leaving no part of the city or its suburban areas uncovered. The challenge lies in finding the optimal number and locations of these vertical farms, particularly in ensuring that the coverage areas intersect in a way that provides full service to the entire population. This process involves determining the minimum number of farms necessary to cover the entire

area while ensuring there are no gaps in service. Through this optimization process, we aim to create a model that can guide the strategic placement of vertical farms and drone bases, ultimately ensuring efficient and comprehensive service delivery for the city of Budapest and its surrounding suburban population.

This study not only highlights the importance of considering geographical and population factors when planning for service distribution but also demonstrates the practical application of mathematical optimization techniques to real-world urban planning problems. The results from this optimization process can inform decisions about infrastructure development, ensuring that resources are allocated in a way that maximizes coverage and benefits for the entire urban and suburban population [6].

The planar bodies $C_1, C_2, \dots, C_n$ cover the planar body B if B is a subset of the union of the bodies $C_1, C_2, \dots, C_n$, i.e.

$$B \subset \bigcup_{i=1, \dots, n} C_i$$

In the literature one can find several results for covering a circle, square, rectangle or a regular triangle with circles (see for detailed results e.g. [6]).

In the following we consider the case if the planar bodies $C_1, C_2, \dots, C_n$ are congruent circles and B is Budapest (see Figure 2 for B). We refer Budapest as B . We assume that the boundary of Budapest is a (non-convex) polygon, and we want to find the smallest radius r such that the circles $C_1, C_2, \dots, C_n$ of radii r cover B . Let $\text{conv}(B)$ be the convex hull of B , i.e. $\text{conv}(B)$ is the intersection of all convex planar bodies which contain B (Figure 3). Observe $\text{conv}(B) = A_1 A_2 \dots A_{15}$ where $A_1 (1.7, 1.42)$, $A_2 (8.72, 0.14)$, $A_3 (10.24, 0.8)$, $A_4 (16.34, 6.78)$, $A_5 (15.86, 9.5)$, $A_6 (15.68, 9.78)$, $A_7 (8.58, 14.72)$, $A_8 (7.46, 15.34)$, $A_9 (7.08, 15.5)$, $A_{10} (4.74, 15.34)$, $A_{11} (0.38, 13.12)$, $A_{12} (0.32, 11.44)$, $A_{13} (0.3, 10.2)$, $A_{14} (1.26, 2.7)$, $A_{15} (1.42, 1.86)$ and $1\text{km} = 0.44247$ on the x and the y axes as well. For the sake of simplicity, we consider the convex hull of B and we cover $\text{conv}(B)$ with congruent circles. Since $B \subset \text{conv}(B)$, if $\text{conv}(B)$ is covered by the circles $C_1, C_2, \dots, C_n$, then B is covered by the circles $C_1, C_2, \dots, C_n$, as well. Let R_n be the smallest radius such that the circles $C_1, C_2, \dots, C_n$, cover $\text{conv}(B)$.

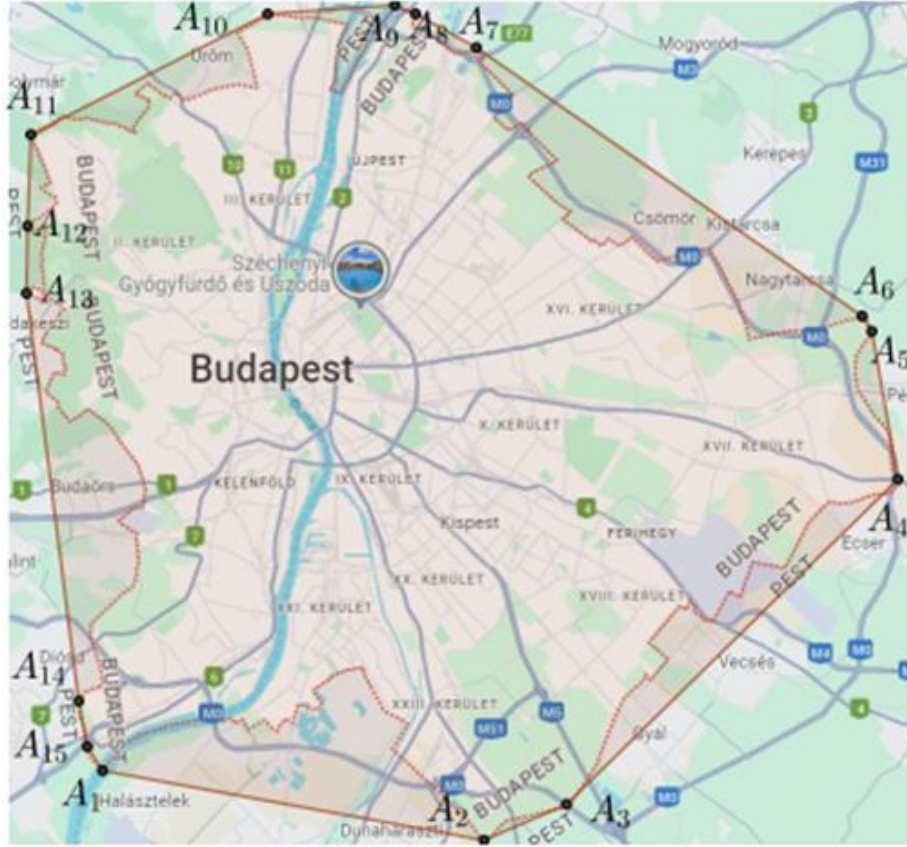


Figure 3: The convex hull of the boundary of Budapest

We consider vertical farms, and we want to minimize the maximum of the transport cost from the considered vertical farm to a specific point of Budapest. The transport cost is estimated by the function $t(d) = \alpha \cdot d$ where d is the distance and α is a universal constant. This means the points of the (boundary of the) circle of radius r and center the considered vertical farm are equal transport costs points.

Theorem 1: Let C_1 be the circle determined by the points A_1 , A_4 and A_{11} . The smallest circle which covers $\text{conv}(B)$ is C_1 .

Proof. If we calculate the circumradii of all the acute or right triangles determined by the vertices and the diameters of the obtuse triangles, then we can realize that the maximum of these numbers is the radius of C_1 , which completes the proof of the theorem.

Let r_1 , be the radius of the circle C_1 . In Figure 4 we can see the circle C_1 and the center of this circle is O_1 . The calculation means, if the position of the vertical farm is O_1 , then the transport cost is less than or equal to αr_1 . Indeed $t(d) \leq t(r_1) = \alpha r_1$.

Theorem 2: Let r_2 be the half of the distance of the points A_1 and A_9 . We have $R_2 = r_2$.

Proof. Let C_2 be the circle of diameter A_1A_9 . Let P_1 (P_2 , resp.) be the intersection point of C_2 and the segment A_1A_2 (A_7A_6 , resp.). Let C_3 be the circle of radius r_2 through the points A_4 such that C_3 covers the points P_1 and P_2 as in Figure 5. Let O_2 (O_3 resp.) be the centre of the circle C_2 (C_3 resp.). Observe, the position of O_3 is not unique. From the arrangement in Figure 5 we have $R_2 \leq r_2$. Now we prove that $R_2 = r_2$. Let us assume that $R_2 < r_2$. We will prove that $R_2 < r_2$ is not true, so $R_2 = r_2$. Let C'_2 and C'_3 be two circles of radius $\varrho/2$ such that these circles cover $\text{conv}(B)$ and $\varrho/2 < r_2$. Without loss of generality, we may assume A_1 lies in C'_2 . Since $A_1A_4 > 2\varrho/2$, the point A_4 is covered by C'_3 . Since $A_1A_9 > \varrho/2$ the point A_9 is covered by C'_3 .

Since $A_9A_2 > 2\varrho/2$, the point A_2 is covered by C'_2 . Since $A_2A_{11} > 2\varrho/2$, the point A_{11} is covered by C'_3 . Thus the points A_4 and A_{11} are covered by C'_3 . Observe, $A_4A_{11} > 2\varrho/2$, a contradiction. This completes the proof of the theorem.

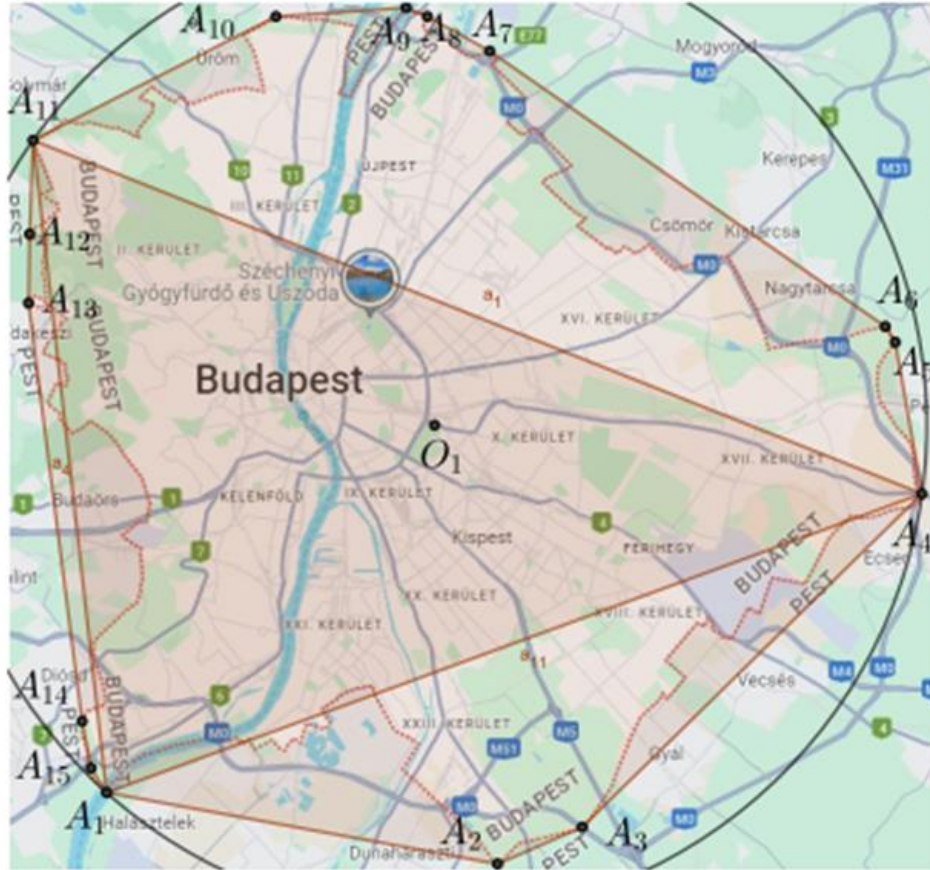


Figure 4: The smallest circle which covers the convex hull of the boundary of Budapest and Budapest as well

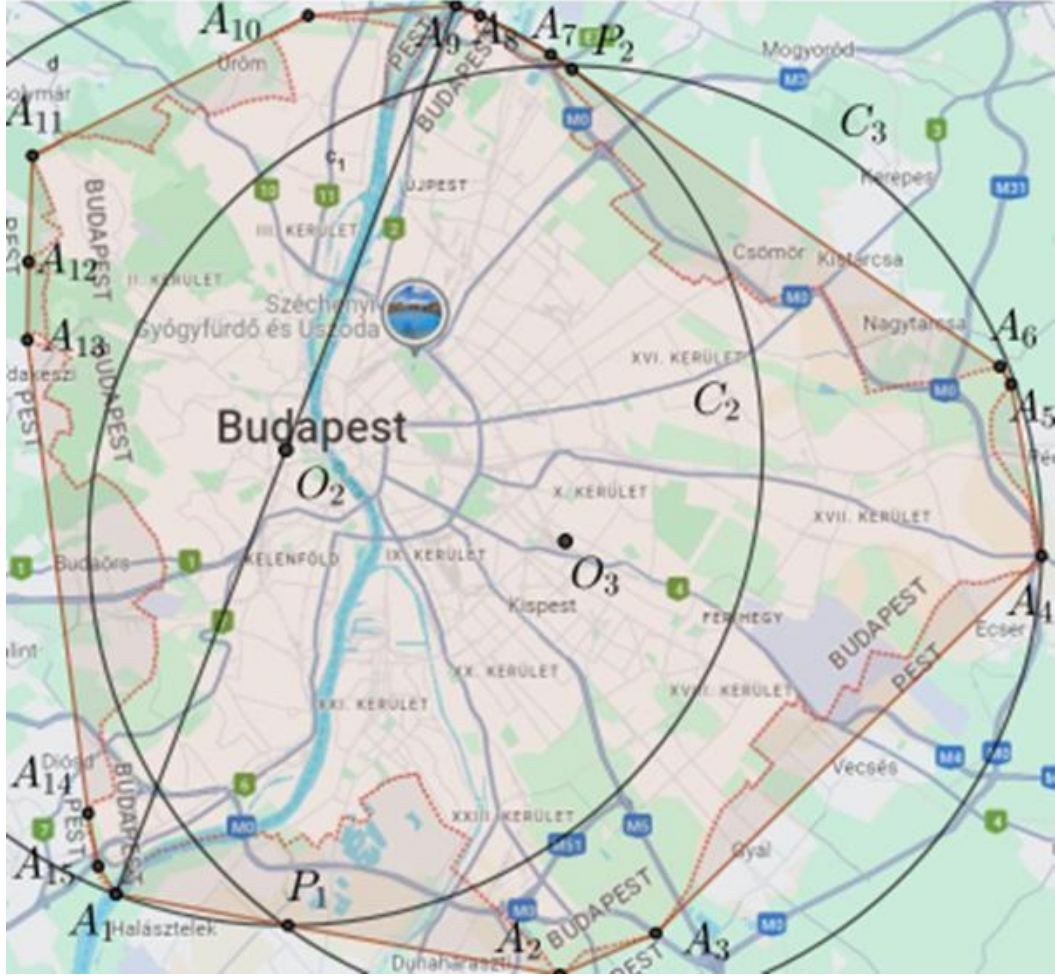


Figure 5: The circles C_2 and C_3

Let P_3 be the point of the segment $A_{13}A_{14}$ as in Figure 6. Let r_3 be the number (close to 5.848074).

Let P_4 (P_5 , P_6 resp.) be the point of the segment A_6A_7 (A_3A_4 , $A_{13}A_{14}$ resp.) such that $P_3P_4 = 2r_3$ ($P_4P_5 = 2r_3$, $P_5P_6 = 2r_3$ resp.). Let O_4 (O_5 , O_6 resp.) be the midpoint of the segment P_3P_4 (P_4P_5 , P_5P_6 resp.). Let C_4 (C_5 , C_6 resp.) be the circle of radius r_3 and center O_4 (O_5 , O_6 resp.).

Let r_3 be the smallest number such that C_4 , C_5 and C_6 cover $\text{conv}(B)$. Observe, $P_3P_4P_5$ is a regular triangle and the angle $P_3A_{11}P_4 > \pi/2$.

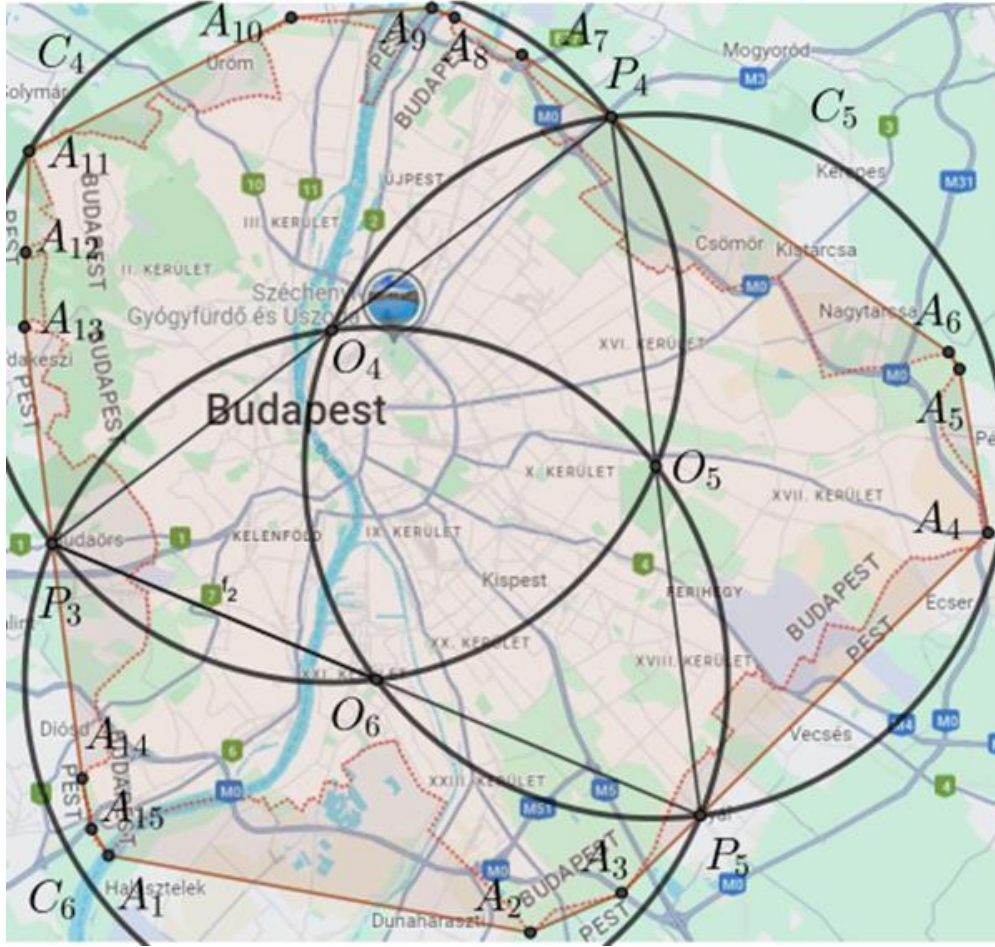


Figure 6: The circles C_4 , C_5 and C_6

Theorem 3: We have $R_3 = r_3$.

Proof. From the arrangement in Figure 6 we have $R_3 \leq r_3$. Now we prove that $R_3 = r_3$. Let us assume that $R_3 < r_3$. We will prove $R_3 < r_3$ is not true, so $R_3 = r_3$.

Let C'_4 , C'_5 and C'_6 be three circles of radius q_3 such that these circles cover $\text{conv}(B)$ and $q_3 < r_3$. Without loss of generality, we may assume A_{11} lies in C'_4 . Since $A_{11}P_5 > 2r_3 > 2q_3$, the point P_5 does not covered by C'_4 . Without loss of generality, we may assume P_5 is covered by C'_6 . Since $P_3P_5 > 2q_3$, the point P_3 does not covered by C'_6 . Since $P_5P_4 > 2q_3$, the point P_4 does not covered by C'_6 . Since $P_3P_4 > 2q_3$, P_3 and P_4 are covered by different circles. If C'_4 does not cover P_3 or P_4 , then C'_5 does not cover P_3 and P_4 , a contradiction. We distinguish two cases.

Case 1. The point P_3 is covered by C'_4 .

Let P'_3 be the intersection point of the circle C'_4 and the segment $A_{13}A_{14}$.

- **Subcase 1.1.**

The circle of radius $2\varrho_3$ and center P'_3 intersects the segment A_6A_7 . Let P'_4 be the point of A_6A_7 such that $P'_3P'_4 = 2\varrho_3$. Observe, P'_4 is covered by C'_5 or C'_6 . Indeed, in any small circle of center P'_4 has an uncovered part by C'_4 in $\text{conv}(B)$. We may assume P'_4 is covered by C'_5 . Observe, P'_3 does not lie in the interior of C'_5 . This means in any small circle of centre P'_3 has an uncovered part by $C'_4 \cup C'_5$ in $\text{conv}(B)$. Thus P'_3 is covered C'_6 as well.

- **Subcase 1.1.1.**

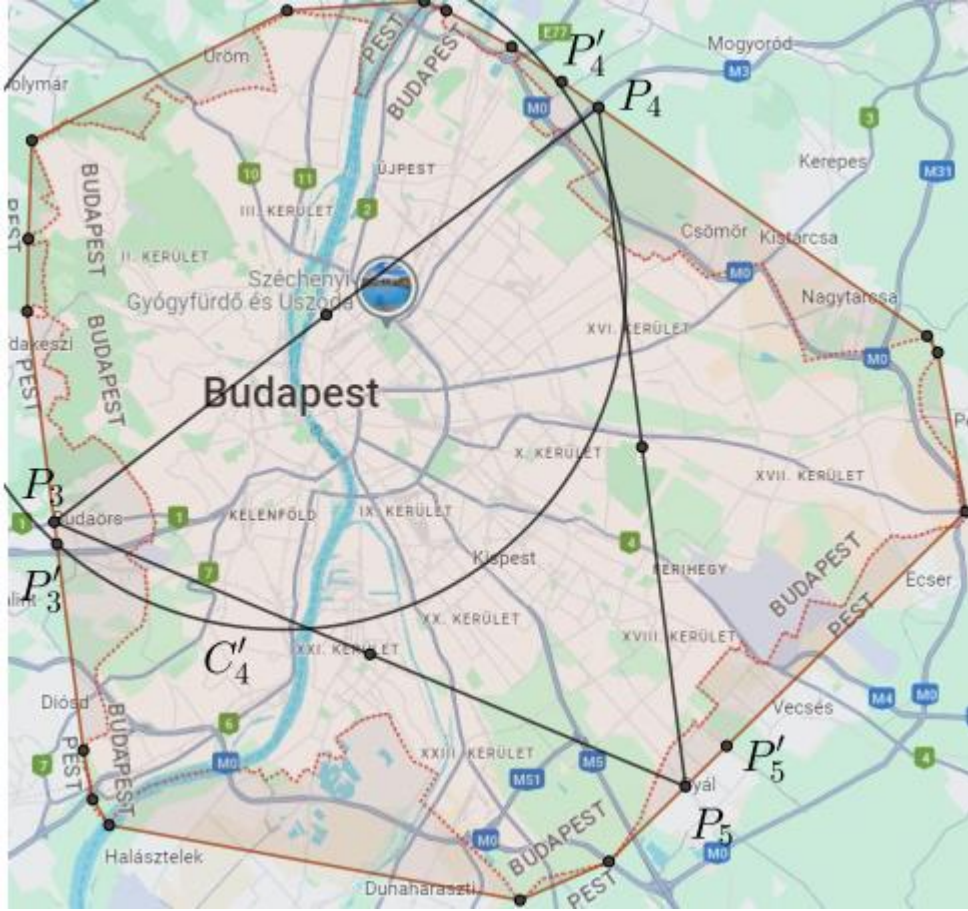


Figure 7: The points P'_3, P'_4 and P'_5

The circle of radius $2\varrho_3$ and center P'_4 intersects the segment A_3A_4 . Let P'_5 be the point of A_3A_4 such that $P'_4P'_5 = 2\varrho_3$. (Figure 7).

Observe $P'_3P'_5 > 2\varrho_3$. Indeed, in the opposite case $P'_3P'_5 \leq 2\varrho_3$ contradicting that r_3 is the smallest radius that the three circles cover $\text{conv}(B)$. Thus P'_3 is not covered by C'_6 , a contradiction

- **Subcase 1.1.2.**

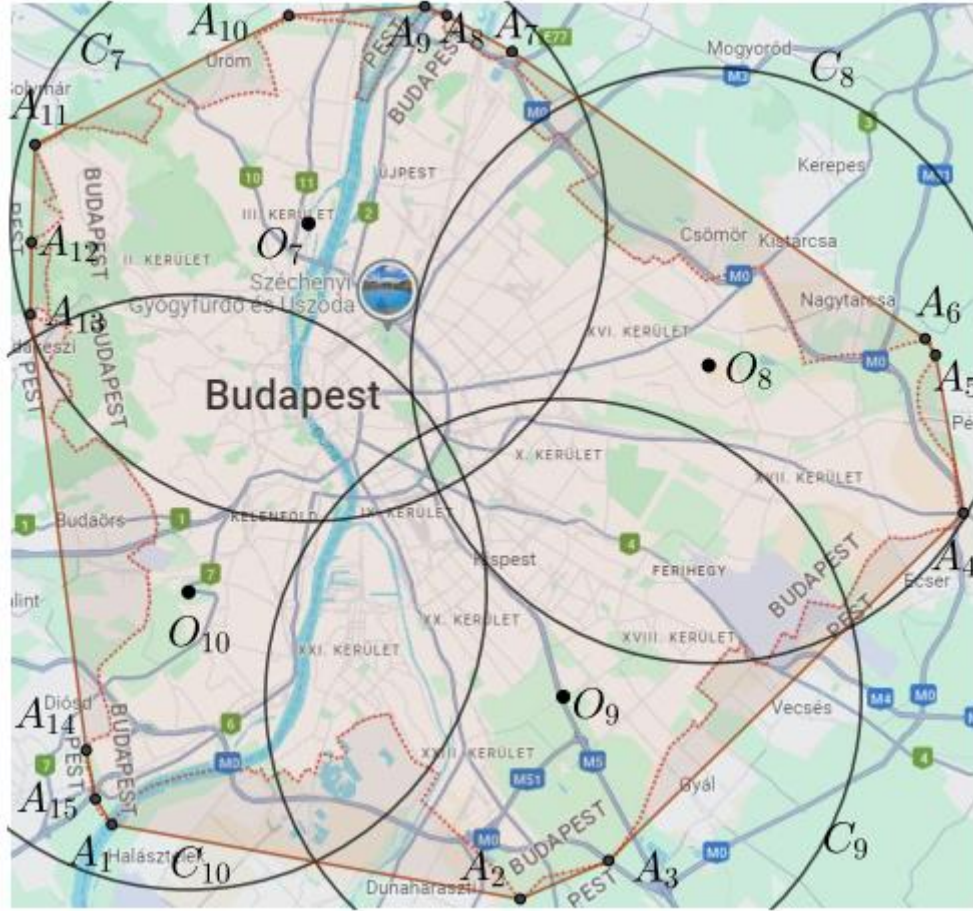


Figure 8: The circles C_7, C_8, C_9 and C_{10}

The circle of radius $2Q_3$ and center P'_4 does not intersect the segment A_3A_4 . Now A_4 is uncovered by C'_5 . Since $A_4P'_3 > 2Q_3$, A_4 is an uncovered point by C'_4 , C'_5 and C'_6 , a contradiction.

- **Subcase 1.2.**

The circle of radius $2Q_3$ and center P'_3 does not intersect the segment A_6A_7 . The proof is similar to the proof of Subcase 1.1.2. Case 2. The point P_4 is covered by C'_4 . The proof is similar to the proof of Subcase 1. This completes the proof of the theorem. Let P_7 be the point of the segment $A_{13}A_{14}$. Let r_4 be the number (close to 5.12). Let P_8 (P_9, P_{10}, P_{11} resp.) be the point of the segment A_6A_7 ($A_3A_4, A_1A_2, A_{13}A_{14}$ resp.) such that $P_7P_8 = 2r_4$ ($P_8P_9 = 2r_4, P_9P_{10} = 2r_4, P_{10}P_{11} = 2r_4$ resp.). Let O_7 (O_8, O_9, O_{10} resp.) be the midpoint of the segment P_7P_8 ($P_8P_9, P_9P_{10}, P_{10}P_{11}$ resp.). Let C_7 (C_8, C_9, C_{10} resp.) be the circle of radius r_4 and center O_7 (O_8, O_9, O_{10} resp.). Let r_4 be the smallest number such that C_7, C_8, C_9 and C_{10} cover $\text{conv}(B)$. Observe, $P_7P_8P_9P_{10}$ is a diamond.

Theorem 4: We have $R_4 \leq r_4$. Proof. From the arrangement in Figure 8 we have $R_4 \leq r_4$

3. Evaluation

The mathematical analysis produced a set of results regarding the optimal placement of vertical farms and drone bases in Budapest, with the aim of maximizing coverage while minimizing the number of required locations. When considering a scenario involving a single site, where the vertical farm and drone base are positioned at the same location, the most efficient and optimal point for placement is marked as O_1 (as seen in Figure 4). In this case, the objective remains to cover not only the entire city of Budapest but also a portion of the surrounding suburban area (the agglomeration). This is because the ultimate goal is comprehensive coverage of the entire capital, ensuring that no areas are left without service. However, this can only be achieved by using a larger coverage area, which is represented by a circle. The challenge here is to select the smallest possible radius that will still provide sufficient coverage, among the many potential configurations.

For scenarios involving multiple locations, the analysis changes accordingly. When two sites are considered, the optimal points for placement are O_2 and O_3 (as depicted in Figure 5). This arrangement splits the service area into two zones, each with a radius that allows for efficient coverage of the city, while still encompassing portions of the suburban area. Moving on to a three-site scenario, the optimal locations for vertical farms and drone bases shift to O_4 , O_5 , and O_6 (shown in Figure 6). This arrangement further divides the coverage area into three distinct zones, reducing the radius of each coverage circle and providing more localized service. Lastly, in the scenario where four sites are established, the ideal locations are O_7 , O_8 , O_9 , and O_{10} (illustrated in Figure 8). This configuration offers the most localized and concentrated service areas, with four smaller circles that collectively cover the entire city and part of the surrounding areas.

When comparing these theoretical, mathematically optimal locations with the reality on the ground, it becomes clear that installing and operating vertical farms at or near these calculated points is technically feasible. In other words, there are no significant technological barriers that would prevent the establishment of vertical farms and drone bases at these locations. For each scenario, whether involving one, two, three, or four sites, the technical requirements for installation and operation are well within the realm of possibility. However, while technical limitations do not pose a major challenge, certain legal and regulatory issues still exist. These may hinder the immediate implementation of vertical farms at the proposed

locations. Addressing these legal obstacles would be a crucial step toward bringing these plans to fruition.

For the scenario involving a single site, the radius of the coverage circle, centered at O_1 , is approximately 16 kilometers. This relatively large radius allows a single farm to provide coverage over a wide area, but it may not be the most efficient solution in terms of localized service. When two sites are introduced, the coverage circles for O_2 and O_3 have a reduced radius of approximately 14 kilometers. This smaller radius reflects the fact that the workload is being shared between two locations, allowing each site to focus on a more confined area. In the case of three sites, with locations at O_4 , O_5 , and O_6 , the radii shrink further, to around 11 kilometers for each coverage circle. This reduction is a result of the increased number of service points, each responsible for a smaller portion of the overall area. Finally, when four sites are used, with coverage circles centered at O_7 , O_8 , O_9 , and O_{10} , the radius is reduced even further to approximately 10 kilometers. This configuration provides the most localized coverage, ensuring that service is as close to the population as possible. All of these distance calculations are based on measurements taken using the distance measurement function of Google Maps, ensuring that the proposed solutions are grounded in real-world geographical data.

One important consideration in any drone-based delivery system is the return journey. When an order is placed from the outer edge of the coverage area, the drone must travel to the delivery point and then return to its base. This means that the total distance traveled by the drone will be twice the calculated radius of the coverage circle. Therefore, the distance a drone needs to travel is an important factor in determining the efficiency of the delivery system. Given this requirement, the construction of four or more vertical farm locations appears to be a viable and practical solution, as it minimizes the distance drones need to travel and maximizes the efficiency of the system.

In Budapest, there are already two prominent vertical farms that can serve as reference points for understanding the practicality of these proposed locations. The most notable of these is **Bedrock.farm**, located at 200 Üllői Street. Interestingly, this site is quite close to the mathematically calculated location of O_3 (as shown in Figure 5). This proximity suggests that the analysis was able to identify locations that align with existing real-world investments. Another significant vertical farm in Budapest is operated by **Csillagváros (Star City) Ltd.**, located at 77 Váci Street in the 4th district. This site is near the calculated location of O_7 (as indicated in Figure 8). However, it's important to note that Csillagváros is primarily

involved in research and development (R&D) and is not currently producing for the commercial market. Nevertheless, this situation may change in the near future, as the farm's five-year maintenance period is nearing its end. Once this period concludes, it is expected that the regulatory environment may become more favorable for commercial production, potentially enabling Csillagváros to enter the market as a significant player.

Both of these existing vertical farms are located within former industrial sites, meaning they represent brownfield investments. This suggests that they have made use of previously developed land rather than greenfield sites, which can often lead to more sustainable and cost-effective development. In the case of Csillagváros Ltd., the crops harvested at the farm are transported by road to their destination. In contrast, Bedrock.farm uses cargo bikes provided by the **Stork Courier** service to deliver fresh produce directly to customers, representing an environmentally friendly approach to urban agriculture and logistics.

The geographical positioning of these two existing vertical farms in Budapest shows some alignment with the optimal locations identified through mathematical analysis. While this alignment may seem notable, it is likely a coincidence rather than a direct result of deliberate planning based on such calculations. Nonetheless, this overlap between theory and reality provides a valuable insight into the practical viability of the proposed locations and suggests that further development of vertical farms in Budapest could be pursued based on these optimal points.

4. Further Focus Points

In this chapter, I am going to talk about some further focus point, where the scope of this essay is being further discussed, and more expanded, also where this theoretical idea is being more investigated to be able to be considered and more easier to imagine it in reality.

4.1. Beyond Budapest

This idea could be further developed and enhanced by expanding the scope beyond Budapest to encompass the entire country. By broadening the analysis to a national level, we could investigate how vertical farms and drone-based delivery systems might function across Hungary, covering not only major urban centers but also rural and suburban areas. Expanding the coverage would introduce additional complexities, such as differences in population density, geographical features, and infrastructure availability, but it would also offer the potential to optimize food production and delivery across a much larger area, improving food security and sustainability at a national scale.

4.2. Non-Flying Zones

Another critical consideration in expanding the concept is the existence of no-fly zones—areas where drone flights are prohibited for safety, security, or regulatory reasons. These zones must be accounted for in the planning process, as they could significantly impact the feasibility of drone-based deliveries in certain regions. For example, areas around airports are heavily regulated to prevent any interference with commercial or military aircraft, making them no-fly zones for drones. Similarly, military bases and other sensitive government facilities restrict drone operations to ensure national security. Additionally, drones are required to maintain a safe distance from the ground, particularly when flying overpopulated areas, to avoid accidents or collisions with obstacles such as buildings, trees, or communication towers. Taking these restrictions into account is crucial for planning a viable and compliant drone delivery network.

4.3. Drones

Beyond regulatory considerations, another important aspect that should be explored is the cost of drones themselves. Different types of drones come with varying price points, depending on their specifications and capabilities. The type of drone selected for use in the vertical farm delivery system would depend on several key factors. First, the load capacity of the drone is an important consideration—larger, heavier drones can carry more cargo but are generally more expensive and may require more frequent maintenance. These drones would be suitable for larger-scale deliveries, such as to wholesale buyers or distant locations. On the other hand, smaller drones with lower load capacities could be more efficient for quick, frequent deliveries to individual consumers, particularly in urban settings.

Second, the range distance of the drone is another factor that would determine which model is best suited for specific regions. Drones with longer flight ranges are necessary for deliveries to rural or remote areas, where distances between farms and consumers are much greater than in urban environments. In contrast, shorter-range drones could be used for more densely populated areas where delivery points are closer together.

Finally, the charging speed of the drones must also be taken into account, especially if a large-scale delivery network is implemented. Drones with fast charging capabilities would be able to complete more deliveries within a shorter timeframe, increasing overall efficiency. However, faster charging systems may be more costly or require additional infrastructure, such as advanced charging stations at each farm or base. Balancing these factors load capacity, range, and charging speed—would be essential in determining which drones to purchase for specific locations and delivery needs.

4.4. The Use of Ecological Solutions

We can also discuss the use of ecofriendly solutions, like the potential for solar energy to power vertical farms. Especially if located on rooftops or in areas with ample sunlight, could install solar panels to generate electricity for all of their operations, from automated plant systems to the drones themselves. Solar panels have become increasingly efficient and cost-effective, making them an ideal solution for energy-hungry vertical farms, which often rely on artificial lighting, temperature control, and irrigation systems. By tapping into the power of the sun, these farms could reduce or even eliminate their dependence on conventional energy sources, such as fossil fuels, thus lowering both operational costs and environmental impact. Solar-powered vertical farms could be especially viable in rural areas

with abundant space for solar installations, ensuring a consistent supply of green energy to support food production.

We can also integrate the use of solar energy in drone technology, as it could also play a transformative role. Although most drones are currently powered by batteries that need to be charged using grid electricity, there is potential to integrate solar charging stations at each vertical farm or drone base. These stations could capture sunlight and convert it into electricity to charge drone batteries, reducing reliance on traditional power sources. In fact, some advanced drone models are being developed with built-in solar panels on their wings or bodies, allowing them to recharge mid-flight and extend their operational range without needing frequent stops. This type of innovation could make drone deliveries even more sustainable, particularly for longer-distance deliveries where battery life is a limiting factor.

In addition to solar power, other renewable energy sources such as wind power and geo-thermal energy could be explored, depending on the geographical location of each vertical farm. Wind turbines could be installed in rural areas with high wind speeds to generate electricity for farm operations, while geothermal energy could be tapped to provide heating or cooling to vertical farms, particularly in areas where the temperature needs to be carefully regulated. Utilizing these clean energy sources would ensure that the system remains eco-friendly and resilient in the face of fluctuating energy demands and market conditions.

4.5. AI and Vertical Farming

We saw from our last encounter with the pandemic that it is easy to lose and weaken our economic and food supply chain, so using vertical farms that offer us not only full control on it but also giving us an easy way to automate this process without any human intervention, with that said emerging it with the new AI technologies will ensure that crops are grown in the most efficient way possible.

Using Robots and AI powered machines in handling manual tasks like planting, harvesting, watering also, associating this with some plant monitoring sensors, will give us robots that are equipped with a well-defined algorithm capable of adjusting care based on the plant's specific needs, incorporating this with AI can help us detect subtle signs of disease in crops before they are visible by the human eye, thus ensuring that no problem can occur.

AI can also play a crucial role in optimizing resource use. Algorithms can analyze data on light, water, heat and nutrient consumption, continuously adjusting the inputs to minimize waste while maximizing output. This not only reduces operational costs but also optimizes sustainability by lowering the farm's environmental impact. Machine learning models can predict the ideal growth conditions for different crops based on historical data, thus tuning everything from artificial light used to the timing of crops delivery.

4.6. Reduction of food waste

Vertical farming and drone delivery can significantly reduce food waste by cutting down the time between harvest and consumption. Traditional agriculture often involves long supply chains, where produce is shipped over long distances, passing through various intermediaries before reaching the consumer. This process increases the likelihood of food spoiling during transport or storage. By contrast, vertical farms can be located much closer to urban centers or even within them, reducing the time and distance food needs to travel from farm to plate.

With shorter supply chains, there is less need for excess packaging or refrigeration, further reducing the risk of spoilage. Drones, which provide fast and direct deliveries, can transport produce within hours of harvest, ensuring freshness and reducing the chances of food being wasted due to overstocking or delayed deliveries.

Additionally, because vertical farms operate in controlled environments, they can produce crops more predictably, reducing the overproduction that often leads to food waste. Using approaches to monitor demand, vertical farms can adjust their output, accordingly, producing only what is needed thus avoiding waste.

This system also allows for more flexible harvesting strategies. Crops can be harvested just in time to meet demand, rather than being harvested all at once and stored for later. By delivering fresher produce directly to consumers, vertical farming and drone systems can help retailers and consumers alike reduce waste at the point of sale and at home.

4.7. Job creation

Vertical farming can create a new whole line of job opportunities, for instance there will be demand for engineers, data scientists, and technicians to develop and maintain the technologies used in vertical farming. These jobs would range from maintaining automated systems like robotic arms that plant and harvest crops, to analyzing the data that ensures

optimal growing conditions inside the farm. In addition to tech jobs, vertical farms will also create traditional roles like farm managers, crop specialists, and quality assurance inspectors.

The drone delivery network further enhances job opportunities. Beyond the drones themselves, there will be jobs in logistics, drone maintenance, and route optimization. New industries could get around drone production, repair, and software development, leading to a huge effect on local economies. Moreover, regions specializing in drone manufacturing or vertical farming technologies could become innovation hubs, drawing investment and talent.

Finally, vertical farms can help revive economically distressed areas by repurposing abandoned buildings or industrial zones, turning them into productive, revenue-generating spaces. This type of “brownfield investment” can contribute to urban renewal, creating a more sustainable urban ecosystem while providing a fresh source of income and jobs for local residents.

4.8. Hungary and future of VF

From my experience and talks with some of vertical farms owners, I really see a lot of potential in vertical farming. Right now, though, it’s true that the products from these farms are on the pricier side, so most of their clients are restaurants. These businesses rely on vertical farms because they get a steady supply of fresh produce, and some of the crops can stay fresh for over one week, which is a big plus for them.

Looking forward, I hope that as Hungary’s economy improves, more people will be able to afford these kinds of products. If that happens, it could encourage more people to try out vertical farming or invest in similar projects, making fresh, locally grown food more accessible to everyone. It would be exciting to see vertical farms become a regular part of the food landscape here in Hungary.

4.9. Summary

In summary, by incorporating AI, automation, eco-friendly solutions such as solar power, wind energy, energy-efficient designs, and electric drones into the vertical farm and drone delivery system, can creates a self-sustaining system where crops are grown, monitored, and harvested with minimal human input. This approach would reduce

dependence on non-renewable resources, cut greenhouse gas emissions, and promote a greener future. Expanding the scope beyond Budapest to include the entire country and even regions beyond while integrating these technologies could create a model for sustainable agriculture and food distribution, setting a powerful example for eco-friendly innovation in urban and rural settings alike. Overall, expanding the vertical farm and drone delivery model to the entire country requires addressing additional regulatory, logistical, and technological challenges. Factoring in no-fly zones, optimizing drone selection based on cost and performance, and ensuring regulatory compliance are all essential to developing a robust and scalable solution that could revolutionize food production and delivery across Hungary. This broader approach could potentially create an efficient food distribution system, bringing locally grown produce to consumers quickly.

5. Resume

Having discussed the various aspects of vertical farming and drone delivery, it becomes clear that vertical farms represent a revolutionary idea that holds immense potential for the future of global food production. However, this concept must be further developed and expanded on a much larger scale to truly realize its benefits. Vertical farming should not remain con-fined to selected cities or regions; instead, it should be scaled up and made accessible to the entire world, regardless of an individual's purchasing power or geographic location. The goal should be to democratize access to fresh, locally grown produce by ensuring that even the most economically disadvantaged communities can benefit from the advantages of vertical farming. Achieving this would require addressing affordability and distribution challenges while ensuring that vertical farming can be integrated into both urban and rural environments around the globe.

One of the most important aspects of optimizing this drone network would be the acquisition of real-time data from the field. By collecting vast amounts of data such as drone flight patterns, delivery times, customer locations, and environmental factors we could continuously refine and improve the delivery strategy. This data-driven approach would provide insights into how to minimize energy consumption, reduce delays, and enhance the overall efficiency of the system. For instance, analyzing data on peak delivery times or the geographical distribution of demand could enable better scheduling and more efficient route planning. Additionally, weather and terrain data could be used to optimize drone flight paths, ensuring that drones take the safest and most energy-efficient routes. Developing this drone delivery system requires not only sophisticated data management but also continual innovation in delivery strategies. Traditional methods of food delivery are often inefficient, relying on outdated infrastructure or systems that cannot scale effectively. In contrast, a drone-based system would have the flexibility to adapt to changing demands, scaling up or down as needed. As we gather more data and insights from early implementations, we can refine the system to create more efficient and sustainable delivery models. Moreover, the development of a sophisticated drone network would provide an excellent opportunity to integrate cutting-edge technologies such as AI and machine learning to enhance efficiency further. AI could be used to predict demand, plan optimal delivery routes in real-time, and even allocate resources like drones and charging stations based on fluctuating needs. Machine learning algorithms could learn from historical delivery data to predict where

bottlenecks may occur and propose solutions in advance, allowing for a much more dynamic and responsive system.

In conclusion, while vertical farms and drone deliveries are already innovative, they hold even greater potential if further developed and expanded on a global scale. Creating an efficient drone network, driven by data and smart delivery strategies, could transform the way food is grown and distributed, making it more accessible, affordable, and sustainable for everyone. By integrating renewable energy sources, smart technologies, and sustainable practices, we could create a new standard in global food production that not only meets the needs of today but also sets the stage for a more resilient and eco-friendly future.

6. Additional Key Considerations

I want to mention an experiment, that is a bit out of the scope of this essay, but it will help advance this idea and make it more closer to reality, which is an experience done by DODO which is a delivering company, where they conducted a live hands on experience a successful drone delivery test in Budapest by the Czech company in partnership with the Rossman drugstore chain [7], which in my opinion is the one of the first steps to make this idea came true, and also will help scratch the surface and facilitate the adoption of drone delivery in Hungary.

Also I want to mention a visit that I was part of, a vertical farm (Mikrozöldseggfarm) specialized in microgreens, which produce green peas, pink radish, turnip..., that are planted in a coconut fiber and sprinkled with only clean water, that means that they don't use neither pesticide nor insecticide, saying that, using organic and certified seeds and growing them in a controlled environment where humidity and temperature are tweaked, their vegetables are ready to be cut after 8-15 days. Here you can find some pictures that were taken in day of the visit.



Figure 9: On site pictures of VF of Mikrozöldseggfarm.



Figure 10: On site picture of a microgreen at Mikrozoldsefarm. Source: Own work



Figure 11: A picture of the package of the microgreens. Source: Own work

7. Acknowledgement

I want to thank mainly my two supervisors, **Dr. György Ágoston and Dr. Antal Joós** who without them I don't think I would have the opportunity nor the courage not to only be one of the co-authors in a research paper, but also in writing this essay, so I appreciate putting their trust on me and I hope that I didn't disappoint. I am very honored to be on this journey with them.

Also, I want to thank Mikrozdsefarm that have let me closer to their vertical farms, and helping me by answering my questions, and correcting some misconceptions, also by allowing me to take some pictures in the visit, and by that using it in this essay.

8. References

- [1] G. Ágoston, H. Aydane and A. Joós, "Geographic optimization of vertical farm installation using drone delivery transport method in Budapest," in *IEEE 7th International Conference AND workshop in Óbuda on Electrical and Power Engineering (CANDO EPE 2024)*, Budapest, 2024.
- [2] G. Ágoston, P. Ferenc, G. H. Klaudia and B. Zsolt, "Vertical farms and smart cities – identification of common research areas, Tungsram's experience and vision in Central Europe.," in *Jiri, Ruzicka (szerk.) 2022 Smart City Symposium Prague (SCSP) Piscataway (NJ), USA: Institute of Electrical and Electronics Engineers (IEEE) (2022)*, 2022.
- [3] C. B, P. F and G. Ágoston, "Transport Demand Model on the Effects of Establishing Vertical Farms in Urban Areas," in *In 20th International Conference on Transport Science ICTS 2022 Maritime, Transport and Logistic Science*, pp. 12–17, <https://icts.sdzp.org/wpcontent/uploads/2024/02/ICTS-2022-Proceedings-CIP.pdf> (Accessed on 17 July 2024), 2022.
- [4] Y. Z, "Food delivery by drone is just part of daily life in Shenzhen," in *MIT Technology Review*. <https://www.technologyreview.com/2023/05/23/1073500/drone-food-delivery-shenzhen-meituan> (Accessed on 17 July 2024), 2023.
- [5] U. Lőrinc, Á. János and G. Ágoston, "Sustainable vertical farming and the aspects of transportation.," in *Emerald Publishing (accepted article for publication)*, 2024.
- [6] F. T. G, "Packing and covering," in *In Handbook of Discrete and Computational Geometry, 3rd Ed. Chapman and Hall/CRC*, Chapman and Hall/CRC, 2017, p. 27–.
- [7] "Logistics of the future: we are testing drone delivery in Hungary," <https://www.idodo.group/content-hub/logistics-ofthe-future-we-are-testing-drone-delivery-in-hungary> (Accessed on 4 Sept 2024), 18 January 2023.

List of figures

Figure 1: Some of Tungsram Agritech products: Growth Cabinet, a mobile vertical farm (left) and special horticultural LED portfolio (right). Source: Tungsram information sheet (Tungsram Agritech, n.d.).	3
Figure 2: The map of Budapest	4
Figure 3: The convex hull of the boundary of Budapest	7
Figure 4: The smallest circle which covers the convex hull of the boundary of Budapest and Budapest as well	8
Figure 5: The circles $C2$ and $C3$	9
Figure 6: The circles $C4$, $C5$ and $C6$	10
Figure 7: The points $P'3$, $P'4$ and $P'5$	11
Figure 8: The circles $C7$, $C8$, $C9$ and $C10$	12
Figure 9: On site pictures of VF of Mikrozdoldsegfarm.	24
Figure 10: On site picture of a microgreen at Mikrozdoldsegfarm. Source: Own work	25
Figure 11: A picture of the package of the microgreens. Source: Own work	25