Generating Optimum Form for Vertical Farms Skyscrapers in UAE

Aref Maksoud[1], Mariam Adel[2], Aysheh Majdi[3], Deena El-Mahdy [4]
[1]Assistant Professor, Architectural Engineering Department, University of Sharjah
[2] Alumni, Architectural Engineering Department, University of Sharjah
[3]Alumni, Architectural Engineering Department, University of Sharjah
[4]Department of Architectural Engineering, British University in Egypt

Abstract:- **The world population is growing rapidly and is expected to reach 9 billion by 2050. This huge population increase requires a massive area to reside in, reducing the land areas that can be used for agriculture. This will result in a reduction in food security for the entire population. Thus, the need for food production technologies is becoming a priority with every passing day.**

Vertical farming is one of the most innovative topics emerging to solve the food production solution. The design process of a vertical farm goes through multiple steps starting with discovering the optimum form. This paper aims to find the ideal model for a vertical farm skyscraper in the UAE while considering the climate conditions and environmental parameters.

The method of study in this article relates to using Ladybug and Grasshopper, a Rhinoceros 3D v6 plug-in, to run simulations analyzing the environmental factors, in order to achieve the main objective of this paper. The analysis following Estidama regulations proved that the best possible form has drastic improvements in thermal comfort, decreasing the perceived heat gain and solar radiation while having more surfaces exposed to direct daylight reducing the dependence on artificial light for the cultivation of crops.

Keywords: Vertical Farming, Skyscrapers, Forms, Food Security, Environmental Behavior, Estidama, Grasshopper, Ladybug, Simulation, Thermal Comfort, UAE.

1. INTRODUCTION

Vertical farming is a modern farming technique that uses a closed controlled environment within skyscrapers and by stacking layers on top of each other to maximize the production of the crops and to maximize the use of the land [1]. It is an efficient sustainable farming method suited in the UAE considering the extreme weather and soil conditions of the UAE climate, UAE's location is in an arid zone, its desert environment occupies more than three-quarters of the total area. Its weather is characterized by low rainfall as the mean annual is around 78 mm covering a period between 9 to 19 days over the whole year, high temperatures and humidity that reaches 46° C and 100 percent respectively in the summer, poor soil as it is severely affected by desertification and lack of natural waterways, all of them have a huge impact on the country's agriculture [2]. Vertical farming contributes to developing the country economically, environmentally, culturally, and socially leading to a sustainable future while following Estidama regulation. The UAE sets systems and programs to follow for the upcoming years to better the quality of life in the UAE, and Estidama is one of the systems, as well as the 2021 vision and UAE national food security strategy 2051.

UAE's National Food Security Strategy 2051 aims to achieve the best food security in the world, by producing sustainable food using modern technologies. One idea that can supply food to cities with sustainable agriculture practices is Vertical Farming [3]. Since the UAE depends on 80% on imports, in 2015 the UAE spent 197$ billion on vegetable products, and in 2018 the UAE spent 232$ billion, which is expected to spend around 617$ billion by 2050 [4]. By starting to have vertical farms in the UAE it can accomplish the security strategy before 2051.

The population size of the UAE increased from 1.0 million in 1980 to 8.4 million in 2010. It is expected that the population will keep on increasing to reach approximately 15.5 million in 2050 [5]. Vertical farming is an efficient method to self-sustain the productions of food for the increasing population.

The design of any vertical farm skyscraper goes through different phases, our research is focusing on the first phase which is the form-finding. The main objective of this research is to generate the most suitable form for a vertical farm skyscraper in the UAE, taking into consideration the environmental parameters, allowing an adequate amount of daylight to enter the skyscraper minimizing the use of LED light for the plants' growth. This to be achieved through experimental studies using ladybug simulations, and comparison between the possible forms using improvement calculation following Estidama regulations.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

2. RELATED LITERATURE

2.1. Estidama and Sustainable contribution of vertical farms design in the UAE

Abu Dhabi's green building rating system, Estidama (Arabic for sustainability), was set up in 2008 under Abu Dhabi's 2030 vision for economics and urban planning, where sustainability is its most emphasized segment. Estidama is built on four main aspects of sustainability that are: Society, culture, environment, and economics, to enhance the life cycle of buildings, not just in the UAE, but in the whole Gulf Region.

Estidama applies the Pearl Rating System (PRS) as its standard in which the main factors of the building's life cycle are considered, including the building's design, construction, operation, and maintenance. This makes the PRS a very suitable option for the Gulf Region, especially that it takes into account the culture of the region, as well as its harsh environment and climatic conditions, and aims to optimize both energy and water consumption all while retaining a comfortable environment inside the building.

The rating system is divided into 7 categories that are necessary to provide a sustainable comfortable living while reducing energy and water consumption, which are: Integrated Development Process, Natural Systems, Livable Buildings, Precious Water, Stewarding Materials, and Innovating Practice. Out of the 7 necessary sustainable growth sections, this research will focus on one essential key factor, which is Resourceful Energy.

While the Resourceful Energy section encourages the use of strategies such as the passive design strategies, it also lays down a minimum increase in energy performance by 12% and Aims to reduce the external heat gain (EHG) by 10% to 15% in contrast to that of the original building [6].

The percentage of improvement can be calculated using the given equation:

$$100 * \frac{BBEHG - PEHG \left[\frac{KWh}{m^2}\right]}{\text{BBEHG}}$$

BBEHG: Baseline Building External Heat Gain

PEHG: Proposed Building External Heat Gain

As for vertical farming, it contributes to developing the sustainability of the country in its three dimensions; socially, environmentally, and economically as Sustainability occurs when all three are thriving.

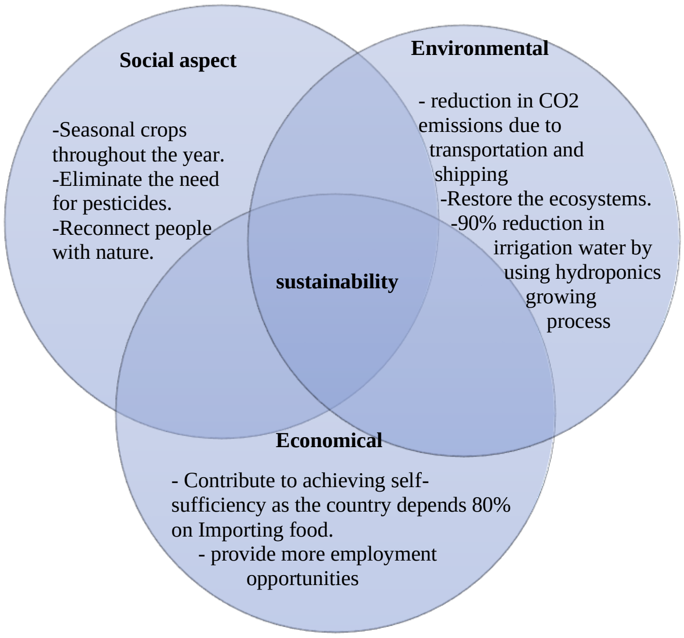


Figure 1 Sustainable contribution in its three pillars

2.2. Design inputs to generate an efficient Vertical farm in the UAE

2.2.1. Vertical farm form

Based on Despommier's book (Vertical Farm) the main four ideas to take into consideration while designing a vertical farm is to capture as much sunlight as possible, gather passive energy for providing a stable source of power, consider plants protection in the design and lastly maximize the growing space of the crops. In this article, our main focus is on capturing as much sunlight as possible since it will have a huge impact on the form of the skyscraper [7].

Another factor that impacts the form is the vertical farm growing systems that are used. There are common ones like hydroponics that is the practice of cultivating crops without the need for soil, instead of using a growing medium such as perlite and coir, with water and nutrients. Within the hydroponic system, there is the aeroponic system that has the highest technology setups. This mechanism revolves around directly targeting the plants' roots by a piping system that ends with a fitted mist nozzle, applying the proportional relationship between a solution particle size and the rate of absorption by the plants.

Another system is aquaponic which contain fish and plants within the system, each benefit from each other. The plants use the fish excretion as a source of nutrients, on the other hand, plants filter the water in the tanks for the fish. In sum, this system is the integration of aquaculture and hydroponics using their benefits and reject their negatives. [1]

But all the previous systems depend on LED Light however a vertical farm in Singapore that was introduced in 2009 used a system called A-GO-GRO, as shown in figure 2, where the crops depend on sunlight. The vegetables are grown in plant racks that rotate around 9-meter-tall towers, by using a water pulley system that is generated by gravity and flowing water to rotate vegetable trays. Each tower has an 8hour cycle to achieve a full rotation, exposing the growing plants to sunlight, avoiding the need for artificial lighting. [8]

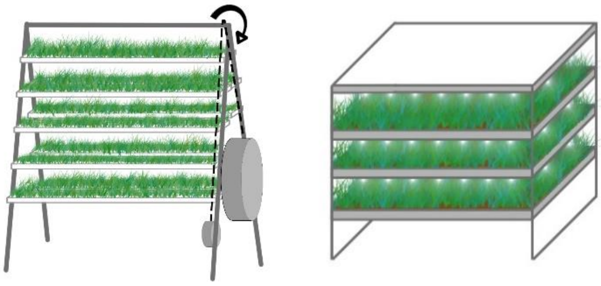


Figure 2 A-GO-GRO system and LED growing shelves system

2.2.2. *Materials that are suitable in the UAE*

The most exterior building material used is concrete. The regular cement used, emit around 900 kg of CO_2 for the fabrication of every ton of cement. To reduce the carbon emissions and the environmental footprint, the use of sustainable concrete with high volume GGBFS; concrete made from ground granulated blasted slag cement, is more efficient as mentioned in Estidama under recycled materials [9].

Another building material that is suitable for the vertical farm's needs is ETFE. Ethylene Tetra Fluoro Ethylene is a polymer that is used instead of glass in modern architecture. It is a clear, self-cleaning, transparent, lightweight material that allows 95% of the sunlight to penetrate the building while providing structure and insulation for the interior. Between its layers, there is a different pressure that helps the screen to close and open changing the sunlight transmission. And with solar coating painted onto the exterior of the ETFE, it can help in generating power. Compared to glass, ETFE transmits more light, insulates better, and costs up to 70% percent less to install [10].

2.2.3. *Green walls*

The use of green walls has a significant impact on the thermal performance of buildings and the urban environment in summer and winter. They minimize the 'urban heat island' effect in cities and regulate the buildings' temperature keeping them warmer in winter and cooler in Summer, by the shade they provide, and the evapotranspiration process that cools the surrounding air. As demonstrated in a previous study in the UAE during July, the temperature at the vegetated areas remained 25°C while in the non-vegetated areas it exceeded 50°C [11]. It saves the buildings' energy by reducing the cooling demand needed for air conditioning and improves air quality by filtering pollutants.

Using native plants in the green wall contribute to the sustainability aspects, some plants in the UAE are adaptive to the weather and require less maintenance in terms of water. Moreover, plants like Mondo grass, Minima Jasmine, Alternanthera, Dusty miller can also help regulate the air temperature around the building as they have proven in studies that they can reduce the humidity around them which is a big factor in the UAE weather [12].

UAE's green rating system Estidama encourages the application of green wall usage in new buildings to reduce the effects of the heat island phenomenon, with a considerate selection of membrane system, irrigation system, insulation materials, and vegetation type. And with the many advantages of green walls, it can gain points in Estidama's different categories like Livable buildings, Natural systems, Precious Water, energy, and materials. Moreover, the use of native plants and minimal water needed in green walls can also gain points.

2.2.4. *Solar panels*

One of the advanced solar panels that are being used in the UAE is Building-integrated photovoltaics (BIPV). They are used to replace materials on the roof and facade of buildings. There is no difference in cost between using the BIPV system compared to the traditional building material cost. Therefore, in the long term, BIPV saves a lot of money compared when using traditional building material for the façade. Another benefit for BIPV that it does not need to change the design to make it fit for a solar panel Since they can be shaped into different forms and colors to fit the design of the building.

Another advanced solar panel type is Building Applied Photovoltaics (BAPV). It is a method that consists of fitting modules to existing surfaces via superimposition once construction has been completed, such as during an energy renovation project. This is the approach adopted for traditional photovoltaic solutions [13].

2.2.5. *Parametric Adaptive Façade*

Parametric design facades can create a form that blends in with the architectural language of the city, forming an elegant, stable, and functional vertical farm. Adaptive facades optimize the form to react to the environmental conditions and the changes in solar radiation allowing ideal shading and maximum use of daylight. As well as they contribute to reducing buildings' energy demand, by protecting the façade in summer from heat gain, reducing the cooling load required, and reducing heating energy needed in winter. Besides, they are more efficient than the fixed ones, as sun shading devices' performance is related to the solar altitude angle and varies throughout the day and year [14].

3. METHOD

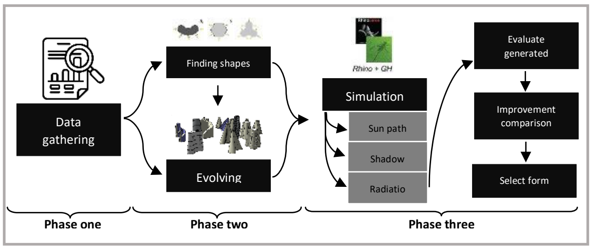


Figure 3 Method chart

The method is done through three phases, the first phase is the literature review process. The search for theoretical vertical farming research and articles were applied using ResearchGate and Google Scholar databases using different keywords. As well as Dickson Despommier; The vertical farm book; which was the base for the form-finding process.

The second phase is generating different forms that fit the vertical farm. The major idea was to form a model that allows the maximum amount of daylight to enter the building for the plants' growth with more surfaces exposed while as well considering the harsh weather of the UAE. The third phase is the key aspect of this research, where all the different models were studied, their energy performance graphs obtained by Ladybug; a tool for grasshopper; were demonstrated, compared, and analyzed following the standards set by Estidama. As each developing model influence was tested to acquire a 10% to 50% reduction in the heat gain compared to the baseline model as required by Estidama Standard.

The method used for finding the exact average radiation value for each side of the curved models is done by getting the number of pixels for each color and then dividing it by the total number of pixels for each side using Adobe Photoshop, then each percentage for different colors is multiplied by its corresponding radiation value and finally taking the sum of them.

Ladybug is an open-source environmental simulation tool. It imports and analyzes weather data from EnergyPlus Weather files ". epw" to Grasshopper, which is a graphical algorithm editor built for parametric modeling in Rhino 3D. It also provides a variety of 2D and 3D designer-friendly interactive graphics to support the decision-making process during the initial stages of design. It provides easy to understand climate graphical visualizations in the 3D modeling interface of Grasshopper to simplify the energy performance analysis process. Figure? shows the workflow of the software and the inputs and outputs received.

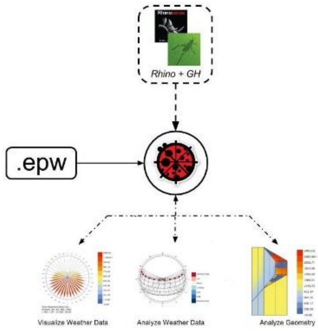


Figure 4 Ladybug workflow diagram

Therefore, by generating multiple codes using the Ladybug, the ideal energy-efficient form can be generated, depending on variable environmental factors such as sun path, shadows, and solar radiation.

The sun path is one of the most informative and useful diagrams to be used for environmental analysis. As sunlight and shadows affect people and their use of

areas all day long and all over the year, therefore, it is important to study the sun's position and movement in the sky. This diagram is a visual aid to establish the solar position in an hour for any day by looking at the azimuth and altitude lines. It provides a direct estimation of how much daylight a building surface is exposed to throughout the year without any further calculations.

The Shadow diagram provides a visualization of how the proposed form cast its shadow and its effect on the surrounding site at different times of the day and dates during the year. The study calculates the received hours of direct sunlight by the geometry using sun vectors from the sun Path component. In the case of this article, it affected even the distribution of plants in the vertical farm that depends on the number of exposed hours of daylight.

Solar radiation is a crucial factor to be considered for the optimal design of a building with regards to human thermal comfort and energy consumption levels. The solar radiation diagram provides a more precise estimation of how much daylight spaces are exposed to. The heat gain for solar radiation results acquired from the analysis required further calculations in order to obtain possible estimations.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

4. GENERATING VERTICAL FARM MODELS

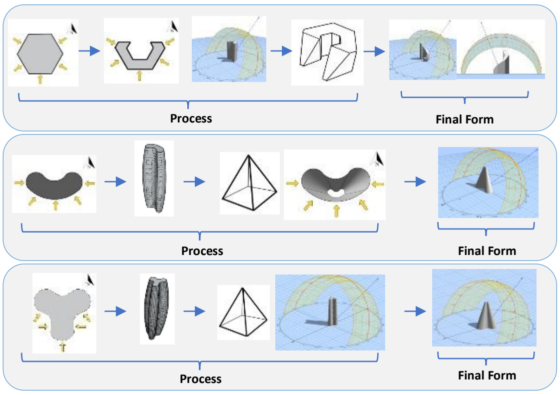


Figure 5 Forms development

This research aims to find the optimal form for vertical farms skyscrapers that work efficiently, depending more on daylight for farming. The first phase is generating different forms depending on this factor, then testing them by multiple parameters. This phase is divided into three approaches shown in figure 5 First starting with a shape that has more surfaces that can be exposed to the direct daylight, such as a hexagonal shape as in the first approach. Then, implementing Despommier's crescent shape into the form and the pyramid idea to allow more sunlight to enter. Finally, breaking the bulkiness of the shape while allowing more daylight to penetrate the form by inclining the roof resulting in a spiral form.

In the next approach, the same idea of having more surfaces was followed by choosing the pronged shape. To follow the architectural language of the city and yet make the skyscraper stand out, the shape evolved into a parametric form. Then applying the pyramid idea to penetrate more sunlight to the shape.

The last approach started by following Despommier's research by having a crescent shape as the base. Then it followed the same evolving steps as the second approach by having a parametric shape following to apply the pyramid idea. All the developing shapes are tested later on in the article to find the best fit for a vertical farm skyscraper.

5. SIMULATION

The third phase main object is to test the different generated models through environmental specifications' codes using Grasshopper and Ladybug, then compare the performance of each to ensure optimal environmental performance form.

5.1. Analyze the environmental parameters

The annual sun path diagram is used to determine the location of the sun throughout the year using the azimuth and altitude lines, showing how much sunlight the building is being exposed to. As shown in figure 6, the analysis period runs on the 21st of June representing the heating period, also runs on the 21st of September representing the transition period in and December, and the cooling period.

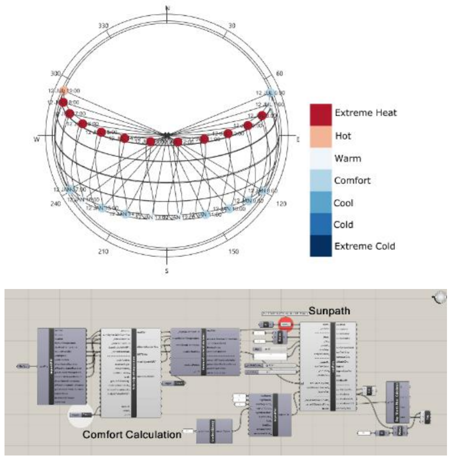


Figure 6 Annual sun path diagram

The shadow diagram uses the sun path vectors to show the shadow projection of the building on neighboring elements. the shadow diagram helps in determining where to place growing systems for vertical farm, also to pick where to place the plants based on the number of hours it is exposed to the sunlight.

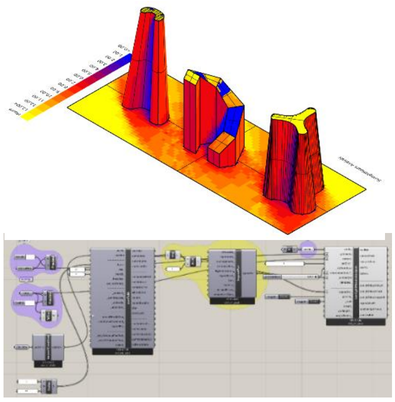


Figure 7 Shadow diagram

For the solar radiation analysis, to illustrate the amount of sunlight space receives, a set of codes were written generating different radiation analyses. To run these analyses, the epw file of Sharjah, the north direction, and the simulation period are the main inputs. The first radiation analysis is the SkyDome analysis that shows the amount of each sky patch by using the selectSkyMxt component. The analysis shows three skydomes

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

illustrating the diffuse radiation, direct radiation, and total radiation. The analysis period was all year long from the 1st of January till the 31st of December. As shown in figure 8, there is not much diffuse solar radiation in the UAE and most of it is direct. Therefore, the aim is to design a vertical farm skyscraper form that receives the lowest impact of direct solar radiation.

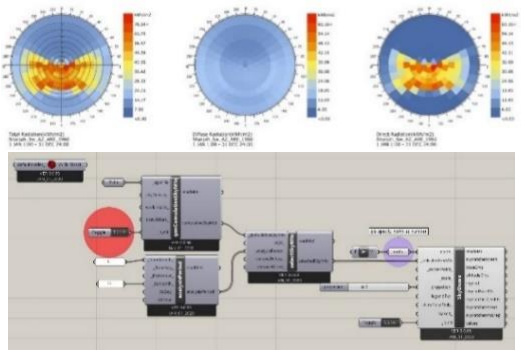


Figure 9 Solar radiation analysis

The second solar radiation simulation is Radiation Rose. This shows the total amount of radiation on a surface or a space from the different cardinal directions and orientations. As shown in figure 9, the north direction receives around 332 kWh/m^2 of radiation, while the south direction is exposed to an estimation level of 1108 kWh/m^2 radiation. This difference is to be considered while analyzing the multiple forms for the vertical farm skyscraper complying with Estidama standards illuminance numbers (250 Lux-450 Lux).

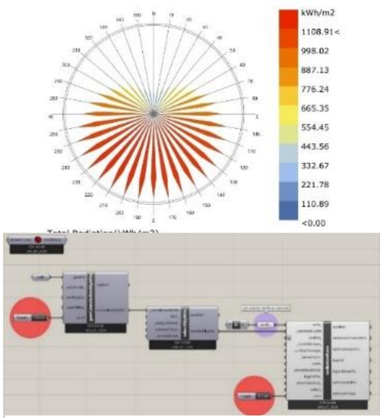


Figure 10 Radiation Rose

And the final radiation simulation is the cumulative solar radiation analysis, which is the main factor to decide the ideal form. This demonstrates the average amount of daylight space receives annually. Therefore, the simulation period is all year long and the north is the +y axis direction as the code shown in Figure 10. With this in mind, the form is to be designed in order to receive the least amount of solar heat gain while allowing the maximum amount of daylight to penetrate through.

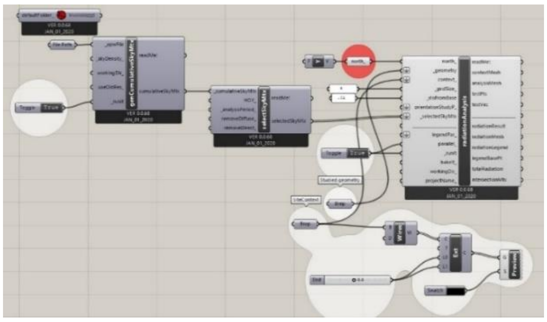


Figure 8 cumulative radiation simulation

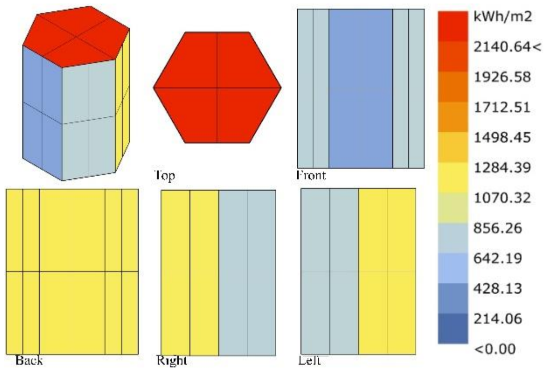
5.2. Analyze the performance of the generated models

In the final phase, the first step is to analyze the performance of the baseline models in each different form, then compare them to the final developing model using Estidama's performance improvement calculation. The ones achieving a 10% to 50% reduction in the heat gain compared to the baseline model will move to the next step.

Then in the second step, the three final models were compared using the same calculation to find the best form.

First Approach:

First, measuring the solar radiation received by each face of the first, second, and third models. As shown in figure 11, the maximum radiation in the radiation scale is 2140.64 kWh/m^2 and the lowest is 214.06 kWh/m^2.



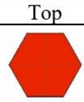
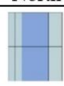
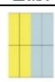
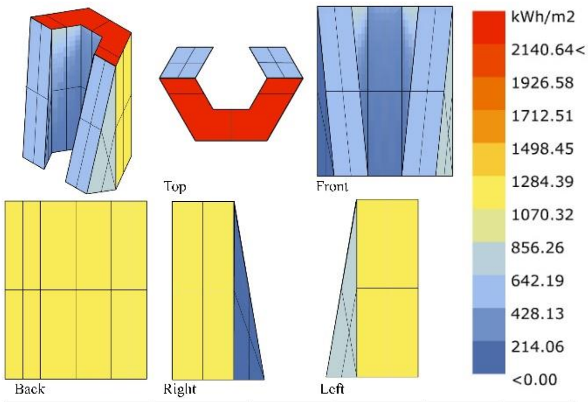
	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	2140.64	535.16	1070.32	856.25	856.25

Figure 11 First approach first model

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

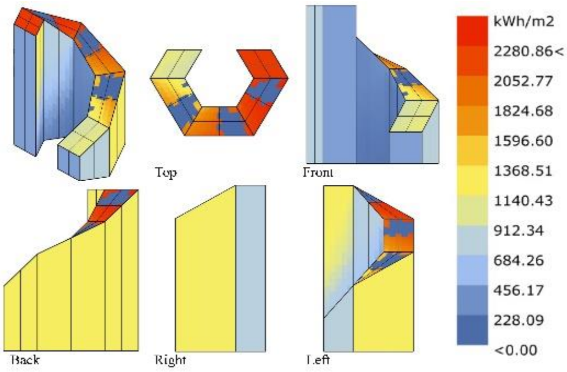
As for the second model, the highest radiation in the radiation scale is 2140.64 kWh/m^2 and the lowest radiation is around 214.06 kWh/m^2 as shown in figure 12.



	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	2140.64	330.08	1070.32	879.17	990.7

Figure 13 First approach second model

For the third model, the maximum radiation in the radiation scale is 2280.86 kWh/m^{2,} as for the lowest radiation is around 228.09 kWh/m^2 as shown in figure 13.

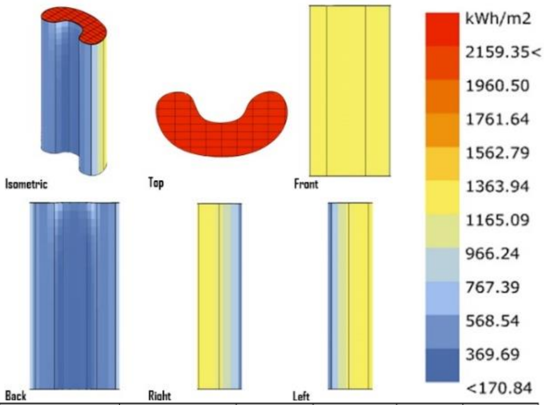


	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	1230.9	319.9	1140.43	978.59	953.8

Figure 13 First approach third model

Second Approach:

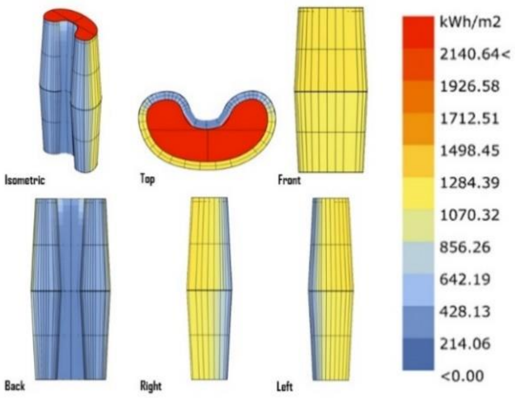
Measuring the radiation for the second experiment for the base, first and second model to measure the improvement in heat gain according to Estidama standards. As shown in figure 14 the radiation scale for the maximum radiation in the first model is 2159.35 kWh/m^{2,} as for the lowest radiation is around 170.84 kWh/m^2.



	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	2159.35	314.8	1165.09	954.6	1012.3

Figure 124 Second approach first model

For the second model, the radiation scale for the maximum radiation in the base model is 2140.64 kWh/m^{2,} as for the lowest radiation is around 214.6 kWh/m^2 as shown in figure 15.



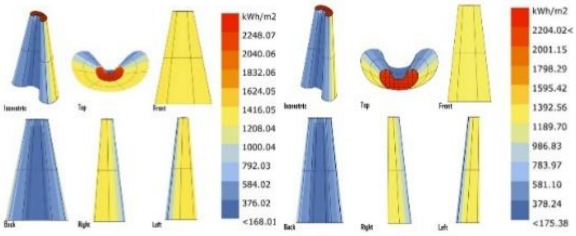
	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	2140.64	552.23	1070.32	912.65	924.75

Figure 14 Second approach second model

For the final form two experiments were done using the same shape but different angles the first model is having all sides tilted but the second model having all sides tilted except the south side. As shown in figure 16, the first model the radiation

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

scale for the maximum radiation in the base model is 2248.07 kWh/m^{2}, as for the lowest radiation is around 168.01 kWh/m^{2}. For the second model, the maximum radiation in the base model is 2204.02 kWh/m^{2}, as for the lowest radiation is around 175.38 kWh/m^{2}.



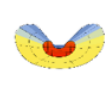
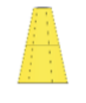
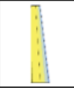
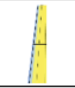
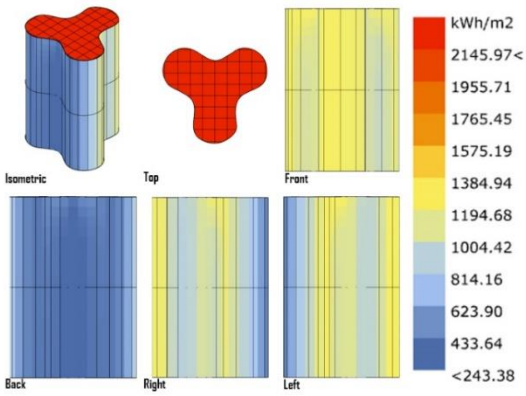
	Top	North	South	East	West
Third model illustration					
Model Radiation (kWh/m^2)	2248.07	371.88	1208.04	1089.5	1063.6
Fourth model illustration					
Model Radiation (kWh/m^2)	2204.02	337.67	1035.7	873	925.6

Figure 15 second approach third and fourth model

Third Approach

For the third approach, three models were made to compare them to each other. For the first model as shown in figure 17 the radiation scale for the maximum radiation in the first model is 2145.97 kWh/m^{2}, as for the lowest radiation is around 243.38 kWh/m^{2}.



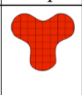
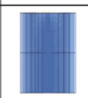
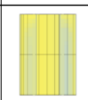
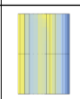
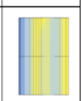
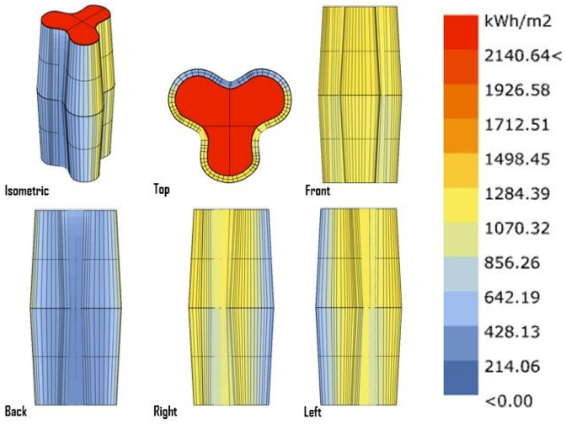
	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	2145.9 7	433.6	1105.3	909.4	913.1

Figure 17 Third approach first model

For the second model, the radiation scale for the maximum radiation in the base model is 2140.64 kWh/m^{2}, as for the lowest radiation is around 214.06 kWh/m^{2} as shown in figure 18.



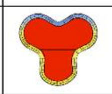
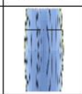
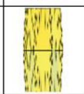
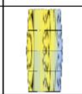
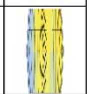
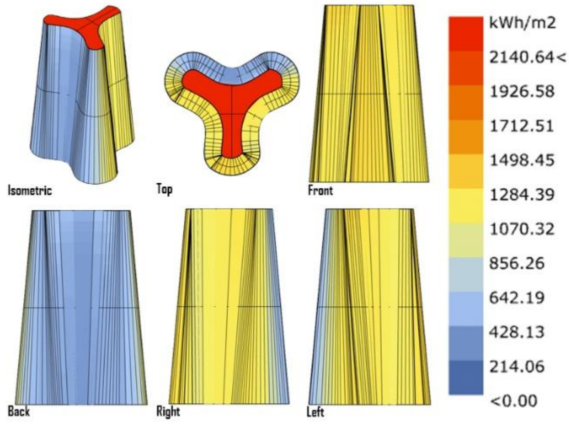
	Top	North	South	East	West
Model illustration					
Model Radiation (kWh/m^2)	2140.64	436	1027.1	873.39	888.37

Figure 16 Third approach second model

For the third model, the radiation scale for the maximum radiation in the base model is 2140.64 kWh/m^{2}, as for the lowest radiation is around 214.06 kWh/m^{2} as shown in figure 19.



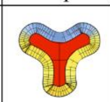
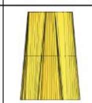
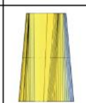
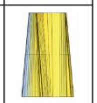
	Top	North	South	East	West
Model illustratio n					
Model Radiation (kWh/m^2)	2146.64	423.86	1113.13	997.5	1018.9

Figure 17 Third approach third model

6. RESULT

This section discusses the major findings of the previously conducted simulation using Ladybug, a plugin in Grasshopper testing different environmental conditions. To get the best suitable form through a comparison over two phases using Estidama's improvement equation, first comparing the base-models performance with each other and choosing the ones that achieve 10% to 50% improvement, finally comparing the final models to find the optimum one fitting in UAE.

First approach

For the first approach, each face of the first and second models was analyzed and compared together. There was 0% improvement in most of the faces, however, only the north-facing side had an improvement of 38.3%. Resulting from that the second model is more fit form for a vertical farm than the first model based on the improvement percentage and having more faces exposed to daylight indicating its eligibility for further comparison.

Table 1 Comparison between the first model and the second model in the first approach

	Top	North	South	East	West
First Model Radiation	2140.64	535.16	1070.32	856.25	856.25
Second Model Radiation	2140.64	330.08	1070.32	879.17	990.7
Improvement (%)	0 %	38.3%	0 %	-2.7%	-15.7%

Moving to the next step in the first approach where the second model was compared to the third one. As table 2 demonstrates, the surfaces of the third model had an improvement in the solar heat gain ranging from 11%-42.5% highest development in the roof and the lowest in the north façade, which fulfills Estidama’s requirement for the radiation received.

Table 2 Comparison between the second model and the third model in the first approach

	Top	North	South	East	West
Second Model Radiation	2140.64	330.08	1070.32	879.17	990.7
Third Model Radiation	1230.9	319.9	1140.43	978.59	953.8
Improvement (%)	42.5%	0.37%	11.21%	23.81%	25.74%

The radiation simulation of the first approach has proven that the third model has the highest improvement and performance compared to the first and second one.

Second approach

For the second approach, the first model was assigned the base model in the Estidama radiation improvement equation and the second model as the proposed model. As shown in table 3 there was almost 1% improvement in the top side, as for the north it had a huge setback by 75%, as for the south and west side they had almost 10% improvement, for the east almost 5% improvement.

Table 3 Comparison between the first model and the second model in the second approach

	Top	North	South	East	West
First Model Radiation	2159.35	314.8	1165.09	954.6	1012.3
Second model radiation	2140.64	552.23	1070.32	912.65	924.75
Improvement (%)	0.9%	-75.4%	8.1%	4.4%	8.7%

The next step is to compare the second model radiation to the third model radiation by making the second model the base model and the third model the proposed one. All sides except the north side had setbacks by 5%-20%. As for the north side, it had improvement by 33.7% as shown in table 4.

Table 4 Comparison between the second model and the third model in the second approach

	Top	North	South	East	West
Second Model Radiation	2140.64	552.23	1070.32	912.65	924.75
Third model radiation	2248.07	371.88	1208.04	1089.5	1063.6
Improvement (%)	-5%	33.7%	-12.9%	-19.4%	-15%

Comparing the fourth model to the second model, by making the second model the base model and the fourth model as the proposed. As shown in table 5 It showed improvement in the north side by 38.9% and in the south by 3.2% and in the east by 4.3%. it showed a small setback in the top by 2.9% and in the west by 0.1%.

Table 5 Comparison between the second model and the fourth model in the second approach

	Top	North	South	East	West
Second Model Radiation	2140.64	552.23	1070.32	912.65	924.75
Fourth model radiation	2204.02	337.67	1035.72	873.02	925.6
Improvement (%)	-2.9%	38.9%	3.2%	4.3%	-0.1%

The comparison between the models showed that the fourth model has the highest improvement.

Third approach

For the third approach, the first model was assigned as the base model in the Estidama radiation improvement equation and the second model as the proposed model. As shown in table 6 there was almost no improvement at the top but for the north, south, and west there were setbacks by 5.6%-19.1%, there was an improvement in the east side by 2.7%.

Table 6 Comparison between the first model and the second model in the third approach

	Top	North	South	East	West
First Model Radiation	2145.97	433.6	1105.3	909.4	913.1
Second Model Radiation	2140.64	436	1027.1	873.39	888.37
Improvement (%)	0.2%	-0.5%	7.1%	4%	2.7%

Comparing the second model radiation and making it the base model in the Estidama equation with the third model radiation and making it the proposed model. It showed setbacks on all sides by 4.1%-20.2%.

Table 7 Comparison between the second model and the third model in the third approach

	Top	North	South	East	West
Second Model Radiation	2140.64	436	1027.1	873.39	888.37
Third model radiation	2146.64	423.86	1113.13	997.5	1018.9
Improvement (%)	-0.3%	2.8%	-8.4%	-14.2%	-14.7%

Based on the comparison between the models it showed that the best model in this approach is the first model as there was no improvement regarding the radiation in the second and third model. Therefore, the three base models with the highest improvement and performance move to the next phase where they are compared together using the same equation from Estidama regulation, to calculate the improvement percentage.

First, comparing the highest improvement model from the first and second approaches; the third and the fourth ones, respectively. The result was that the second approach model had a little improvement only on the south, east, and west façade that does not achieve Estidama requirement, while on the top and north side had a higher radiation exposure, especially on the roof. Resulting that the first approach model has the best performance compared to the second one.

Then, comparing it with the third approach model following the same criteria, the third model showed an improvement on the south, east, and west surfaces, that does not meet the required by Estidama regulations for most of them, however, the top and north-facing surfaces showed a huge radiation increase. Therefore, as the first approach model has the highest improvement percentage compared to the second and third one, it is chosen as the best fit vertical farm skyscraper model in the UAE.

	Top	North	South	East	West
1st approach third Model Radiation	1230.9	319.9	1140.43	978.59	953.8
2nd approach fourth Model Radiation	2204.02	337.67	1035.72	873.02	925.6
Improvement (%)	-78.06%	-5.55%	9.18%	10.79%	2.96%
1st approach third Model Radiation	1230.9	319.9	1140.43	978.59	953.8
3rd approach second Model Radiation	2140.64	436	1027.1	873.39	888.37
Improvement (%)	-73.9%	-36.3%	9.9%	10.8%	6.9%

7. RECOMMENDATIONS AND FUTURE STUDIES

From the simulation conducted in this paper and the analysis, different aspects of the vertical farm can be developed and studied. This article shows a prototype design that can be placed anywhere in the UAE without a specific site, thus for future studies, the orientation should be fixed as it was one of the main affecting aspects in the analysis.

For the material used for the vertical farm that can be suitable in UAE's climate, the north façade has the lowest radiation and heat gain, therefore, ETFE can be implemented on the north-facing walls to allow daylight to enter reducing the dependence on LED light for the plants' growth. The east, west, and south sides have the most sun radiation exposure, thus, applying green walls on part of the façade can reduce the heat gain while providing an aesthetic view for the skyscraper.

As well as, on the south side, control rooms can be designed where the employees can monitor the cultivation floors, using smart glass to control the amount of light and heat getting through the building, while also having hanging plants from the building openings and windows to help shade and insulate the interiors while providing fresh air.

The high radiation in the roof and the south side can be utilized by implementing the BIPV system to suffice the energy demand required for the vertical farm. Finally, the main material to use in the entire project is sustainable concrete, as it reduces energy consumption by using less Portland cement and it is more resistant to temperature changes, reduce CO2 emissions, durable, last longer, and cost-saving.

Applying a parametric adaptive façade in a vertical farm skyscraper can add an aesthetic view to the building while providing ideal shading to the façade and allowing a moderate amount of sunlight to penetrate.

For the plants and their systems arrangements, the shadow analysis can be the main factor to use. There are 3 different types of plants based on the amount of light they perceive. The fully shaded plants that require around 2-4 hours of light, can be placed in the areas that have the lowest sunlight hours. While the full sun plants can be grown in the parts that are exposed for maximum hours to the direct sunlight as they require 6-8 hours of light. Finally, the partially shaded plants need light for around 4-6 hours.

8. CONCLUSION

The purpose of this paper is to find the most suitable form for a vertical farm skyscraper and improve it to be implemented in the UAE while considering the UAE's harsh climate.

This study is divided into three phases. The first phase consisted of collecting information about vertical farming and its different system types, in the second phase the collected information was used to find suitable shapes for the building and improving them. Three different approaches were found and for each approach different models were generated. The models were analyzed in the third phase using Ladybug and Grasshopper to find the radiation for each side of the models, then compared between each other using Estidama's performance improvement equation to find the most suitable model for the vertical farm.

The results show that in the first approach, the third model had the highest radiation improvement by having 42.5% improvement in the top, 11.21% in the south side, 23.81% in the east, and 25.74% improvement in the west. As for the second approach, the fourth model had the highest improvement by having 38.9% in the north and 3.2% in the south, and 4.3% in the east. In the third approach, the second model had a slight improvement by 7.1% in the south and 4% in the east, and 2.7% in the west.

After comparing the results, the third model of the first approach showed the highest improvement in radiation analysis making it the most promising model to be implemented for a vertical farm skyscraper in the UAE.

9. REFRENCES

[1] O. M. t. A. M. L. S. K. Fatemeh Kalantari, "A Review of Vertical Farming Technology: A Guide for Implementation of Building Integrated Agriculture in Cities," *Advanced Engineering Forum*, vol. 24, pp. 76-91, 2017.

[2] F. a. A. O. o. t. U. Nations, "AQUASTAT Country Profile – United Arab Emirates," Food and Agriculture Organization of the United Nations, Rome, Italy, 2008.

[3] S. Elborno, "Food Security: Top Priority," *Emirates NBD Research*, 2019.

[4] "What does import? (2015): OEC - The Observatory of Economic Complexity," [Online]. Available: https://oec.world/en/visualize/tree_map/hs92/import/are/all/show/2015/.

[5] Future Directions International Research Institute, "The demographic Profile of the United Arab Emirates," [Online]. Available:https://www.futuredirections.org.au/wp-content/uploads/2014/11/uae.pdf.

[6] Abu Dhabi Urban Planning Council, The Pearl Rating System for Estidama, Abu Dhabi, 2010.

[7] D. D. Despommier, The Vertical Farm: Feeding the World in the 21st Century, Thomas Dunne Books, 2010.

[8] K. Al-Kodmany, "The Vertical Farm: A Review of Developments and Implications for the Vertical City," *Buildings*, 2018.

[9] T. A. E. A.-A. Mohamed Elchalakani, "Sustainable concrete with high volume GGBFS to build Masdar City in the UAE," *Case Studies in Construction Materials*, vol. 1, pp. 10-24, 2014.

[10] Y. Z. Y. S. Timothy Heath, "Vertical Farm: A High-Rise Solution to Feeding the City? " in *CTBUH 2012 9th World Congress*, Shanghai, 2012.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

[11] M. A. Haggag, "The use of green walls in sustainable urban context: with reference to Dubai, UAE," *Eco-Architecture III*, vol. 128, p. 10, 2010.

[12] J. Z. K. K. S. B. T. P. S. S. K. T. S. K. Hasnain Alam, "Landscaping with native plants in the UAE: A review," *Emirates Journal of Food and Agriculture*, 2017.

[13] K. S. P. B. Mary Debbarma, "Comparison of BIPV and BIPVT: A review," *Resource-Efficient Technologies*, vol. 3, no. 3, pp. 263-271, 2017.

[14] J. L. A. Z. C. M. Marta Barozzi, "The Sustainability of Adaptive Envelopes: Developments of Kinetic Architecture," Procedia Engineering, vol. 155, pp. 275-284, 2016.