Design of a vegetable production model: Z-farming

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Abstract. Currently, climate change is a limiting factor in agriculture, due to the changes in periods and intensity of rainfall, extreme temperatures which generate economic losses and shortages of food. In addition to this factor, population growth and migration to the cities establish the need to seek strategies to guarantee food security and sovereignty, through the so-called urban gardens. From this concept comes a new and visionary subtype of agriculture called Z-farming, which includes the production of food in vertical environments, without using soil and available in open spaces close to cities or completely closed. The “Semillero de Investigación en Tecnología Electrónica Aplicada, Centro de Biotecnología Industrial, Servicio Nacional de Aprendizaje, Palmira”, developed an automated system design for plant production, which aims to raise awareness about food production in small spaces, in order to provide a tool for food production. The design includes the improvement of product characteristics with emphasis on shape, function, and use, with a priority focus on the end user. The project aims to develop a prototype of an automated plant production system as a strategy for innovation and research in sustainable agriculture.

1. Introduction
One of the main problems for the contemporary society and one that will surely be the main problem for future generations is the problem of food security. Due to different conditions of overpopulation and economic-political issues, predictions of food shortages are important. In addition to this, the scenarios commonly included in the phenomenon known as climate change include climatic conditions that further aggravate the problem of food security, for example, the conditions for growing food in rural locations precarious in the face of variations in extreme climates.

In this context, it is necessary to think of innovative solutions. One of them known as urban agriculture (UA) proposes various ways of artificially constructing the conditions for growing food in cities. Zero-acreage farming (Z-Farming) is a type of UA based on food production in vertical environments, without using soil and open spaces close to cities or completely closed.

This research proposes the design of a prototype of a partially closed automated system for Z-Farming plant production. It is based on a design concept that alludes to human consciousness, about food safety. As described above, this paper presents the theoretical basis for the food safety problem to be solved and the design concept of the z-farming prototype. Thus, the notions of climate change, food security, UA and Z-Farming are addressed. Secondly, the results focused on the design proposal are presented. At this point, it concentrates on illustrating the product concept, the design concept, the construction process and the characteristics of the prototype.
2. The impact of climate change and food security
Climate change is any change in the climate over time, whether is due to natural variability or as a result of human activity [1]. Thus, large, generalized and abrupt changes have been detected throughout the geological record. However, given the current high levels of human consumption, combined with constant population growth, they have a negative impact and contribute to the acceleration of natural change [2].

Climate change scenarios include higher temperatures, altered rainfall, and higher CO₂ concentrations in the atmosphere [3]. By the end of the 21st century, Central America is expected to experience a variation in rainfall of between 22% and 7%. In South America, heterogeneous changes are also expected: the northeastern region of Brazil will have a reduction of 22%, while in the southeastern part of South America an increase of 25% [4]. The region will be affected by intense and more frequent phenomena, such as the Southern Oscillation phenomenon (also known as the “El Niño” phenomenon), oscillations in the Atlantic Ocean and tropical cyclones, among others. Due to the increase in humidity in the atmosphere, climate variability is likely to intensify. This means that a greater incidence of extreme events associated with precipitation is expected, which directly affect the performance of reproductive systems [3,5].

In this context, there are two strategies for responding to the potential risks and impacts of climate change: (1) mitigation, which involves policies and interventions to reduce greenhouse gas (GHG) emissions, or improve the sinks of gases that remove them from the atmosphere (e.g., forests and vegetation), and (2) adaptation, which is based on preparing for and minimizing the impact of climate change [5].

Since agriculture is directly dependent on environmental conditions, it is vulnerable to climate change [3,6]. In general, this activity can be affected in three ways. First, increased atmospheric CO₂ concentrations have a direct effect on the growth rate of crop plants and unwanted plants. Second, changes in temperature, rainfall, and sunlight influence the productivity of plants and animals. Finally, rising sea levels cause the loss of farmland due to flooding and an increase in the salinity of groundwater in coastal areas [3]. With changes in temperature and rainfall patterns, variations in the distribution and intensity of pests and diseases are expected, and with the decrease in rainfall levels, less water will be available for irrigation. Increases in average temperatures are expected during all months of the year, as well as daily thermal oscillation. By the end of the 21st century, increases of more than 2 °C are expected for Latin America and the Caribbean [4].

This will affect the duration of the physiological stages of crops (which are based on the accumulation of cold hours and degree days for their development), and increased water resource requirements to meet the demand for evapotranspiration. Due to the decrease in snow storage in high peaks, there will be a decrease in river flows and less accumulation of water in aquifers [6]. There will also be an increase in the "zero isotherms", resulting in increased runoff [6]. In some territories, the impacts will be a serious threat to the sustainability of agriculture, especially in arid and semi-arid territories, where the availability of water for irrigation is already scarce, and where future scenarios of greater water narrowness are predicted.

With the variability in climate behavior, it becomes more difficult to predict the future conditions that will allow us to conclude with certainty that new crops will perform as well as before. In other words, climate change is associated with uncertainty in decision-making, both for farmers and for public policymakers, because even when they can improve the conditions for developing new crops, the risk of obtaining negative results is greater [6]. In the face of this climate change scenario, the need for solutions to guarantee food security emerges, and among the contemporary solutions to this challenge are those related to Urban Agriculture (UA), such as Z-Farming, which is detailed below.

3. Urban agriculture, automated systems and zero-acreage farming
A new and visionary subtype of UA is the Z-Farming [7]. Z-Farming includes all types of food production in and on urban buildings and is characterized by the non-use of arable land or open spaces,
Thus differentiating forms of UA related to building from those found in urban parks, gardens or vacant lots.

Z-Farming’s production types include roof gardens, rooftop greenhouses (RTG), edible green walls and additional innovative forms such as indoor farms or vertical greenhouses. Z-Farming is used as a general term to include all possible types of UA in and on buildings, integrating all types of similar concepts ranging from open roof gardens and integrated agricultural construction i.e., the practice of locating high-performance hydroponic greenhouse systems in mixed-use buildings to Skyfarming [8] or vertical agriculture defined as growing plants or animal life in skyscrapers or on vertically inclined surfaces [9].

Z-Farming practices range from community-based rooftop agriculture to commercial flagship projects that use high-tech green architecture and are applied differently in various parts of the world [10,11]. For the commercialization of Z-Farming, evidence of economically viable models has already been provided, mainly in the United States and Canada [11]. Internationally successful examples are Lufa Farms (Canada), Gotham Greens (USA), Brooklyn Grange (USA), Sky Greens (Singapore) or Urban Farmers (Switzerland) [7].

Soil, water, technical support, and adequate micro-scale composting facilities are the basic elements that cities need to enable a Z-Farming solution. Although UA can be costly, experience shows that this is not necessary [12,13]. For example, soil decontamination can be very costly, but cultivation techniques such as surface planters and hydroponics, allow even contaminated soil to be used for food production.

Returning to the context presented in the previous section, cities face global challenges such as population growth, increasing urbanization and climate change [1,2]. Thus, new approaches increasingly address the interconnection of energy, water and food in cities [14], because spatial and temporal disconnection of food production, consumption and disposal leads to long transport routes, increased traffic and energy-intensive heating, cooling and recycling systems [7]. UA has been considered a solution for climate change adaptation, as it can play a significant role in greening the city while stimulating productive reuse of urban organic waste and reducing the energy footprint.

From the previous perspective presented, it can be thought that social innovation designed more ecological alternatives to satisfy needs, improve political and environmental rights as a new form of ecological citizenship. One aspect to highlight in this regard is that with the UA can reduce the consumption of food involving the use of oil for transport.

There is a close relationship between the food system and climate change [15]. Modern food production, processing, packaging and distribution practices have made a significant contribution, contributing almost 25% of total Greenhouse Gas (GHG) emissions. Energy-intensive production processes and long-distance transport of food products are two important sources of GHG emissions. On average, food production and processing require 20 calories of energy to produce 1 calorie of food. In comparison, in 1910, this ratio was 1:1.

Transporting food from fields to processing plants and supermarkets adds additional energy to the food consumed. Food packaging also uses large amounts of energy and petroleum materials. A study in the Kingston-Ontario region suggested that if 58 common foods, which currently travel approximately 4685 km from source to retailers, were produced entirely in the country, a reduction of ~2100 t of annual greenhouse gas emissions could be achieved. In turn, climate change makes the food system vulnerable due to changing weather patterns and extreme weather events. Undeniably, the transformation of the food system should be a priority [15].

UA can have important benefits for local microclimates by increasing vegetative cover, surface permeability, and rainfall retention. In particular, UA helps reduce the urban heat island effect [16]. An urban heat island (UHI) is an area that is significantly warmer than its surroundings, mainly due to large stretches of mineralized surfaces (e.g., asphalt, concrete) that absorb solar radiation and increase air temperatures near the surface. UHIs are a serious threat to public health, not only because of the direct risk of heat but also because extreme heat exacerbates air pollution. During the warmer months, there is an increase in evaporation, resulting in drier urban soils, which already receive little hydration due to
high mineralized surface coverage \[17\]. In addition, UHIs increase energy demand due to increased use of air conditioning, leading to an increase in global temperature. Numerous studies have shown that vegetation is the most effective way to reduce UHI because it increases the number of permeable surfaces, increases albedo surface area (the extent to which an object reflects solar radiation), and cools the air through vegetative transpiration \[16\]. Vegetation also improves air quality by trapping particles and other air pollutants.

A crucial element for different types of UA to be successful has to do with the implementation of automation systems applied to crops. An automated system, in the context of AU, can be defined as a system that, with the help of technology such as control, communication and programming, allows processes to be optimized and standardized, achieving autonomous performance of tasks that are traditionally carried out through the intervention of human labor. Thus, this type of system can reduce production losses, defects and repetition of human physical labor, which could benefit the cost-benefit ratio. Such automation implies the implementation of various hardware and software systems that include information management, in such a way that actions and programmed processes are controlled and executed to create microclimates, apply nutrients or pesticides that are conducive to plant development \[17\].

In order to implement an automated system of this nature, it must be assumed that it is a complete work that requires multidisciplinary support, at least from different areas of engineering (systems, agronomy, robotics, etc.) \[17\]. However, this characteristic, far from being a disadvantage, can be seen as an opportunity in different areas such as education, since it is propitious to promote not only environmental education, but also multidisciplinary education, as Ponce, Carrera & Molina's study proposes \[15\]. Thus, according to these authors, the creation of projects on automated greenhouses can be seen as living laboratories in which multidisciplinary engineering training is promoted in developing countries \[15\].

Some authors indicate that in the UA and agriculture in general in Latin America, the various technological tools available to automate various processes and make plant production more efficient are frequently wasted \[17\]. Some of the possible causes are the lack of knowledge of these technologies and the high cost speculated for their creation and acquisition \[13\]. However, as indicated above, there are some proposals that adjust to low costs \[14\] through, for example, the implementation of free software applied to small-scale crops \[18\]. So, within the systems required for the creation of an automated system, the interaction of electrical, electronic (where the automation programming itself resides), computer, mechanical, hydraulic and structural systems is required \[18\].

For the development of electronic systems, some of the software used for the implementation of automated plant production systems are Arduino and Matlab-Simulink-MPLAB \[18\]. However, automation of this nature is often accompanied by computer systems for the automation to be carried out over long distances; so, technologies are also required that make use of the internet of things (IoT), Bluetooth, Wi-Fi connections, data processing models and applications for mobile devices \[19\]. Thus, for example, the work of López, González, Olvera & García \[19\] applied a data model for sending and processing information in the FIWARE cloud.

4. Results

The previous revision forms the context for the design of a Z-Farming plant production model is conceived. This design proposal is detailed below and aims to raise awareness about food production in small spaces, in order to provide a tool for food production in urban contexts.

4.1. Product concept
As for the product concept, the proposal is defined as a partially closed automated plant production system module. It is defined for the production of plants from the moment of zero seed placement until the mature stage for the extraction or for the production of seedlings to be transplanted, which depends on the size of the plant species. The design is proposed so that the plant is placed in laboratories to carry out tests and research on the development of this plant and also for its possible use in indoor homes as
a functional decorative object to promote food security. This will have partial automation of the cultivation process with modern electronic systems and the manual use at the time of sowing, the supply of nutrients and extraction in the mature stage of the plant, using materials resistant to corrosion and water (stainless steel, acrylic).

4.2. Design concept

The concept of design is defined as a proposal to raise awareness in the human mind about the problem of food safety. Through a continuous process of evolution in the project, it was defined that the design of the system must make a call to become aware of a great problem that we are facing all over the world, as described in previous sections, and in which we must provide innovative solutions that contribute to food security and help the use of rational and efficient use of water. In the design, the ergonomic model of the breadbasket is taken as a reference and the shape of the human head is used.

The systems that would integrate the design were also defined. First, the design has a structured system, composed by Housing, Base, Door, Containers, Lids, Hinges and Support. Secondly, an electrical system, composed of polarized cables and jumpers. In third place, an electronic system in charge of the automation of the product, composed by (i) sensors of: temperature, humidity, pH, ultrasound, illumination and electro conductivity; (ii) controllers: Raspberry Pi 3, Arduino mega; (iii) actuators: Submersible pump, electro-valve, LED lights and fans; and (iv) a hydraulic system, composed by hoses and clamps.

Once the systems were defined, the technical plans were elaborated, the renders were generated and a first artisan prototype of tests was made, built in wood. After checking and validating the correct functioning of the system and the correct location of the sensors and actuators, the last plans for the construction of the final prototype and the manuals for the use and maintenance of the equipment were elaborated. Finally, the graphic design of the web interface for remote control and monitoring was defined, the product image (logo, POP material) and the product packaging were defined, as well as the information that must be included in the product packaging.

4.3. Prototype design

During the design concept stage, 13 design proposals were elaborated, of which the most appropriate one was selected according to the selection criteria from checklists, and the design concept was defined, which consists, as mentioned above, in raising awareness and leading to reflection on food security. The design defined the conditions of transparency, visibility, water and air circulation, embedded systems and non-fixed control and monitoring interfaces, based on a creative brainstorming process.

The prototype of the closed plant production system has the abstract shape of a human head and consists of a rigid structure of Plexiglas + printed ABS + steel plate, containing hydraulic, pneumatic and mechanical equipment, controlled by an automation system and controllable from control software interfaces. The module has a volume of 250 m³ (0.40x0.90x0.60 m) of the domotic hydroponics module DHM, with density of 5 g - 10 g of seed per m², for the production of foliage, with a maximum weight of the seedlings (level of mechanical requirement of the support racks), with ideal conditions of seed installation, with 1.3 liters of water per plant during its complete cycle, containing fertilizers to dissolve nitrogen, potassium, magnesium, phosphorus and minor. The connection to the electrical network must be 110v, with measurement of ventilation, temperature, lighting, RH, pH, electrical charges. The main equipment should be a rack of seedlings, automation control, monitoring system (remote). Complementary equipment considered for the system are a water filter, water pump, dispensers, ventilation system, misting system, and lighting system.

The control of the system is done by means of an automated remote electronic system based on Raspberry Pi and Arduino, which will receive signals from the sensors in charge of monitoring the different climatic variables inside the closed system of vegetable production and making decisions about which action must be executed to control the different climatic variables. Additionally, a linked software is being developed in the web which it is possible to control and visualize remotely in the parameters captured by the sensorial part from the electronic system.
Finally, it is important to mention that for the prototype was defined by the vegetable species to work is coriander because it is a short cycle horticultural (40 to 60 days). The climatic conditions for the plant are temperature between 18 °C to 20 °C, relative humidity 75%, lighting between 1000 to 7500 lumens and 400 to 700 nanometers, pH between 6.5 and 7.2, irrigation with complete solutions from the salts of nitrogen, potassium, magnesium, phosphorus, and minor. Hydroponic foam and pumice stones are used for the substrate. The design of the prototype can be seen in Figure 1.

![Figure 1. Z-Farming prototype design.](image)

5. Conclusions
The research proposed a design of an automated system for plant production, which aims to raise awareness about food production in small spaces, in order to provide a tool for food production in the context of food security and climate change. The design was based on the abstract form of a human head containing a compendium of automated systems for harvesting plants indoors, thus alluding to raising awareness in the human mind of the food security problem.

It is expected that the usefulness of the design will be used in urban contexts of research in laboratories and, in the future, in homes, not only as a decorative resource but, above all, as a contribution to food security in homes.

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