Sustainable Gardens for Smart Cities using Low-Power Communications

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***Abstract*— This paper presents a study on smart gardens in a smart cities context, a topic that has been gaining more and more interest from the public due to the numerous problems that are felt both in terms of environment and food consumption which, due to population increase and migration towards capital cities, have become a sustainability problem as agricultural production is moving further away from the consumers thus making it harder to obtain fresh goods such as fruits and vegetables. Using IoT combined with new communication technologies such as LoRa that has low-power and wide-area network capabilities, it is possible to create systems that enhance sustainability through a more efficient use of resources while making users more involved with the plant cultivation process and, therefore, develop more empathy towards this topic and sustainability in general. Several smart garden systems and contexts in which those systems are implemented will be analyzed to understand what can be done within this research field.**

Keywords—IoT, Smart Cities, Smart Garden, Sustainability, LPWAN, LoRa

I. INTRODUCTION

The world population increase is expected to reach 9 billion by 2040 [29]. With the growing number of people relocating to cities, there is an increase in pollution, soil degradation, impermeable layers, concrete constructions, and deforestation [2, 31]. In space-constrained urban areas, demand for food, particularly vegetables, will escalate to levels never seen before [5, 29].

In agricultural activities, the watering process is one of the most important factors due to the shortage of water in most regions of the earth [4] and is expected to affect 50% of the world population by 2030 [25]. Irrigation now accounts for 70% of total water use worldwide [5] due to inefficient and archaic irrigation methods. To manage resources and increase production, the agricultural sector needs both science, and industry to improve its effectiveness, efficiency, and innovation [10]. Smart agriculture reduces time, labor, and resources wastage, resulting in higher productivity and crop yield [11]. Urban agriculture, which is a process of farming in an urban setting [3] is adopted in different ways and for different reasons. For instance, the need for nature and greenery in developed countries, particularly in urban areas, is symptomatic of a deterioration in the natural environment [34]. However, in developing countries, this type of activity is seen as a basic and widely adopted option for food production and safety [3].

The Internet of Things (IoT) consists of devices that connect to the internet and communicate with each other [14]. IoT is present in many smart city applications like smart transportation, smart energy, smart infrastructure, smart waste management, and many more. All those applications in a smart city are introduced as interlinked systems that enable valuable and critical information to be securely exchanged among many devices in multiple domains [6]. According to the Ericsson Mobility Report, it's expected that by 2022 the world will reach 29 billion connected devices [22]. Key emerging trends such as cloud computing, the rapid availability of low-cost botanical sensors, and seamless ubiquitous connectivity are some of the driving factors behind the rapid proliferation of such technologies. Sensors not only assist in monitoring the quality of the crops but also facilitate in tracking various environmental factors such as temperature, absolute humidity, soil moisture, air quality, wind speed, and solar intensity [12]. IoT can assist agriculture with applications such as smart gardens, water maintenance, and other automatic installations based on human actions [25]. This type of technology plays an increasingly vital role in constructing smart garden systems due to the necessity to capture real-time environment data to develop an effective strategy to reduce reliance on manual labor while increasing efficiency, product yield, and quality [9, 27]. IoT is capable of efficiently monitoring and managing resources, thereby, enhancing productivity and mitigating global food shortages and water scarcity [12].

A. Motivation

There is a growing public interest in adopting home-based plant-growing systems, as well as a need to expand access to controlled-environment agriculture in urban settings. Increasing interest is partly due to a rise in hobbyist activities, as well as social benefits of growing plants and the attractive, aesthetic value of plants [3]. Apart from being a sustainable approach for producing food, smart gardens have other advantages for cities, including the potential to develop social bonds in communities. Home gardening is also seen as an important new trend for raising societal awareness about environmental issues [6]. The rising interest in health promotion and quality of life, especially in developed societies, is now fuelling societal attention on the health-related benefits of the green area [34].

Agriculture can take advantage of the IoT paradigm [2], Indeed, to efficiently face some future trends, such as world population growth, climate change, and natural resources depletion, as mentioned previously, a fully optimized and sustainable agricultural must be reached [15]. For the growth and cultivation of crops, parameters including fields and the growing condition of plants are vital. Farmers have usually applied regular strategies for all crops which has led to less yield for some specific crops that require specific conditions [9].

Smart gardens are to shift dependence on large-scale agriculture and commercial organic products [16], by giving people the ability to cultivate their plants with little to no actual physical labor on their part [27]. Current trends predict that by 2025 smart autonomous systems will combine over 1 trillion IoT devices with a 50% increased demand for latency-sensitive (real-time) applications [29].

B. Objectives

The main objective of this study is to understand the current paradigm of smart gardens. Both in terms of the context in which these systems are applied as well as the main components, technologies and possible applications for these systems.

This analysis aims to provide de necessarie information for a future implementation that is suitable for the context and needs that this kind of system will require.

II. Related Work

This chapter focus on reviewing studies related to the topic of the paper. A systematic literature review (SLR), a methodology proposed by Kitchenham [35] was carried out to collect relevant information, which will later be analyzed, for the topic addressed in this study.

The IEEE, Scopus, Web of Science, and Google Scholar databases were used to find relevant studies to the topic addressed in this SLR. Using a set of keywords ("smart garden", "IoT", "vertical garden", "community garden", "LoRa" and "sustainability") along with inclusion and exclusion criteria, that ensure the relevance of the studies, a set of 55 articles were obtained. After further analysis of this set of articles, 34 proved to be relevant to the present study.

In section A, the information found in the conducted SLR about the smart garden context and its importance is described to better understand the different application scenarios and the importance of smart garden systems in such environments.

Section B presents an overview of the different parts that make up smart garden systems, from controllers, sensors, communication technologies to the different applications and tools used in these systems.

In section C, the information gathered is summarized in tables that illustrate systems proposed by the authors. From the different components to the main contributions of these proposals, this section allows a broader view of the work developed in the literature on this specific topic.

A. Smart garden context

This section consists of an analysis of the smart garden context and importance as well as the possible application scenarios and key features and benefits of the different types of smart gardens, presented in the literature.

1) Tradicional agriculture.

Traditional agriculture is known for not utilizing advanced technologies, since large-scale agriculture, in most parts of the world, cannot afford to implement and maintain this type of technologies. Traditional agriculture relies on human labor to do tasks such as planting, watering, and harvesting [6]. The type of cultivation methods used, due to its archaic nature, result in considerable waste of resources by not taking into consideration the real conditions and needs of the plants [9].

2) Modern agriculture.

Despite the prementioned reality, agricultural production methods are experiencing a tremendous technological transition [15]. Crop conditions can be taken into consideration using accurate and precise cultivation equipment required for data collection, and the method used to cultivate each can be adjusted accordingly. In this sector, technology, such as IoT, plays a key role in enhancing productivity while also lowering extra manpower, water, and fertilizer requirements, as well as allowing for real-time monitoring of plants [21].

3) Smart management system.

Smart management system in the context of agriculture consists of monitoring and controlling environmental parameters either automatically or remotely [9]. Parameters such as soil moisture, humidity, temperature, pH or light, are influenced by a variety of factors including season, geography, type of soil, and type of plants [5, 8]. Considering that different crops need specific conditions, with a proper smart management system it is possible to monitor and control the conditions in which the plant is being cultivated and, thereby, optimize those conditions and used resources [9].

4) Smart irrigation system.

One of the main resources in the agricultural sector is water and, due to the scarcity of fresh water in most regions of the planet [4], it is of paramount importance to manage this resource appropriately. The amount of water that plants require at various stages throughout their lives, as well as the water hygroscopicity of the soil in the root zone, are critical factors in determining the frequency of the watering process and the amount of water that must be supplied each time [8].

Smart irrigation systems, one of the most recurrently proposed system by the literature in the context of smart agriculture, attempt to increase the quality of plant growth in gardens and fields by irrigating at the right times, with the right amount of water, while considering soil moisture levels and specific irrigation needs in each place. The purpose of such systems is to increase productivity while reducing human effort and avoid water wasting [25]. Smart irrigation systems help in reducing resources wastage, as mentioned, but also help by conserving energy and time. The human error component is also eliminated when manual irrigation is replaced with an automatic system [5].

5) Urban Agriculture.

Urban agriculture can be defined as the process of cultivating plants within and around cities to produce, processing, and distribute food and crops [23]. Apart from the food production aspect, cities can benefit a lot from green spaces [31]. Green spaces in cities have a huge impact on the urban environment by performing a range of crucial tasks, such as reducing air pollution, cooling the air, giving shade and habitat for arboreal birds, creating oxygen, lowering building energy use, providing wind protection, etc. [19]

The author [23] defines urban agriculture in two types, Uncontrolled Environment Agriculture (UEA) and Controlled Environment Agriculture (CEA). Plant cultivation in a UEA setting is practiced in areas such as community gardens, outdoor home gardens, and rooftops. Greenhouses, vertical or multi-story farming, and indoor home gardens are examples of CEA. Environmental factors such as light, temperature, water level, and carbon dioxide concentration are managed and monitored in CEA so that plants and crops can thrive in their optimal environments.

6) Smart home garden.

In a vast number of developing nations, as well as in numerous peri-urban areas of more developed regions, household crops and other small-scale non-professional crop gardens form an important element of the food supply chain. As a result, they constitute a significant economic activity with a great potential for IoT-based techniques to have a positive influence [24]. With smart home gardening, fresh, healthy food crops can also be grown at home throughout the year, whether indoors or outdoors. It can also contribute to a healthy environment in smart cities by promoting a sustainable urban lifestyle [6].

7) Vertical garden.

Due to the fast expansion of urban areas that causes green spaces to become increasingly scarce, determining how to plan urban green space in constrained areas and optimizing the spatial structure of urban green space is critical [19]. One possible answer to this problem is to promote the wider acceptance of the concept of vertical cultivation, which involves the use of indoor farming systems in an uncontrolled environment where every ecological component can be monitored and regulated. Plants can be grown in vertically stacked layers in building facades or even inside buildings using vertical gardens [29]. Vertical gardens can increase food production while maintaining quality and efficiency in urban farming [29].

To create a vertical garden, several factors must be considered at the same time, including effective watering, climate-appropriate plants, the suitable orientation of the facade to receive adequate sunlight, the use of recyclable materials, and a reasonable cost. A vertical garden is made up of numerous plants that are arranged and placed in the vertical plane rather than the horizontal ground of a regular garden [30].

8) Hydroponic garden.

The hydroponics technique is a method of growing plants without the use of soil and with the help of fertilizers [33]. The roots of the plants directly absorb the mineral fertilizer solution contained in the water which ensures that the plant grows at a faster rate in a healthy environment. Providing artificial atmospheric conditions is also a necessary aspect to ensure plant growth, which can result in a 25-30% increase in production and yield [33]. This type of garden, due to its highly controlled nature, needs a system that can secure monitorization and control of the different environmental parameters and so it can greatly benefit from using an IoT-based system to ensure these needs.

B. Smart garden systems

This section reviews the current paradigm of smart garden systems and consists of an overview of the different types of technologies and resources that composes these systems, as well as the proposed systems presented in the literature.

1) Smart garden systems overview.

Using IoT in the agricultural context makes it possible to implement systems composed of several IoT devices that can sense and communicate with other devices in their surroundings, extracting relevant contextual data that can be intelligently processed for a variety of applications and services essential to the cultivation of plants [12]. There are numerous automated' plant growing systems being used [22]. These systems have several parts such as controllers, sensors, communications, and applications that make possible numerous features such as monitoring, visualization, and control of different parameters. The conducted literature review revealed that the vast majority of systems proposed in the literature are irrigation systems that mainly differ in the type of applications and scenario in which they are implemented.

2) Controllers.

When looking at controllers, which are the main control unit of IoT systems, it is important to choose a controller considering the needs of the system itself and its inherent complexity. In this research, most of the authors proposed Arduino or Raspberry nodes as the main computing unit, either combined or by itself, some of which with additional communication modules. Arduino has a vast range of microcontrollers for different purposes and offers a versatile, open-source, low-cost, and simple-to-program platform. Despite that, Arduino is not built to manage applications with a high degree of complexity due to its scalability difficulties. Raspberry controllers, on the other hand, offer strong computational capabilities that allow more demanding applications and algorithms to be implemented [5].

3) Sensors.

Sensors are extremely important in the IoT ecosystem because they are devices that convert electrical signals into digital signals that are then incorporated into systems as variables that represent different parameters of the physical world [27]. With this research, and considering that most systems are irrigation-based, sensors most often used are those of temperature, humidity, and soil moisture. The soil moisture sensor happens to be the most prominent, since it is the one that allows an assessment of the soil conditions, in terms of water level, which is one of the most important aspects when growing crops and it is where significant savings are possible to make.

4) Communications.

Communications technology is a fundamental part of any IoT system. It is the part responsible for connecting devices and sharing information between those devices and the applications that composes the system [5]. Communication technologies have different trade-offs in terms of power consumption, cost, latency, bandwidth, range, and coverage [15]. Wireless Local Area Network (WLAN) (i.e.: Wireless Fidelity version 6 (WiFi-6)), Bluetooth, Cellular (i.e.: Global System for Mobile Communication (GSM), Long Term Evolution Advanced (LTE-A), 5G), and Low Power Wide Area Network (LPWAN) (i.e.: Sigfox, Narrowband Internet of things (NB-IoT), Long Range (LoRa)) [35]. Looking at the system proposals made in the literature, Wi-Fi is by far the most used communication technology. The author [5] mentioned that accessibility and the fact that most low-cost IoT devices normally support Wi-Fi, as well as the sufficient coverage for small-scale applications provided by Wi-Fi, is a possible explanation for why this technology is so recurrent in the literature.

C. Summary

The information present in the previous collected studies will be summarized in this section. To this end, three tables were created, addressing the different contributions of the authors.

Through the analysis carried out on smart gardens, the importance of this topic in terms of environmental sustainability became clear, as described in section A. Some application scenarios have been presented, such as smart home gardens and vertical gardens, to demonstrate some scenarios in which this type of systems can be implemented. In the following Table I, the authors' contributions are divided by the type of environment (UEA and CEA) and the application scenario to summarize the proposed scenarios discussed in the literature.

TABLE I. Smart garden system environment type and implementation scenario.

Type of environment	Contribution	Reference
Uncontrolled Environment Agriculture	Home garden (outdoor)	[5], [10], [11], [13], [14], [15], [24], [25],
	Community garden	[2], [8], [16], [20], [28], [32]
	Vertical garden	[29], [30], [31], [34]
Controlled Environment Agriculture	Home garden (indoor)	[3], [4], [6], [12], [17], [18], [21], [26]
	Hydroponic/Aquaponic	[1], [23], [33]
	Greenhouse	[9], [22]

The main components, such as controllers, sensors, and communication technologies, as well as the applications and tools used in the systems proposed in the literature are described in Table II. This table provides an overview of the current state of smart garden systems, also described in section B which allows for a better preview of what can be done to contribute to this field of research.

TABLE II. Smart garden systems composition.

Ref.	Controllers	Sensors	Comms.	Apps.
[1]	Not specified	Temperature, pH, turbidity,	LoRa	Not specified
[2]	NodeMCU mini D1 module with ESP8266	Temperature, humidity, light, soil moisture	Wi-Fi	React, node.js, MongoDB
[3]	Arduino UNO, Raspberry Pi 4	Temperature, humidity, light, pH	Wi-Fi	Google Sheets
[4]	Raspberry Pi	Temperature, humidity, light, soil moisture	Wi-Fi, Bluetooth	Not specified
[5]	ESP8266, Raspberry Pi	Soil moisture	Wi-Fi	qToggle
[6]	Arduino UNO, ESP8266	Temperature, humidity, soil moisture	Wi-Fi	ThingSpeak
[8]	NodeMCU v2 LUA with ESP8266	Temperature, humidity, soil moisture	Wi-Fi	Blynk
[9]	NodeMCU ESP8266	Temperature, humidity, light, soil moisture, gas	Wi-Fi	ThingSpeak, Blynk
[10]	Arduino Mega 2560, Raspberry Pi 3	Soil moisture	Wi-Fi	Node-RED
[11]	Arduino YUN, NodeMCU ESP8266	Temperature, humidity, soil moisture	Wi-Fi	ThingSpeak
[12]	ESP32	Soil moisture, water level	Wi-Fi	Thingsboard, PostgreSQL
[13]	Arduino UNO	Not specified	Bluetooth	Arduino Bluetooth Home Automation android app
[14]	Arduino UNO, NodeMCU	Temperature, humidity, light, soil moisture, barometric pressure	Wi-Fi	Blynk
[15]	Raspberry Pi	Temperature, humidity, soil moisture, soil temperature	Wi-Fi, LoRa	MongoDB, IOS mobile app
[16]	WeMos D1 mini	Temperature, humidity, soil moisture	Wi-Fi	PHP, HTTP server, Google Firebase
[17]	Arduino Mega 2560, ESP8266	Temperature, humidity, soil moisture	Wi-Fi	Blynk
[18]	Intel Galileo Gen 2	Soil moisture, biometric, light, rain	Wi-Fi	Eclipse (ADK)
[21]	Raspberry Pi3	Temperature, humidity, soil moisture	Wi-Fi	ThingSpeak
[22]	Raspberry Pi	Temperature, humidity, light	Not Specified	ThingSpeak, LabView, Unity, Visual Studio, C #, Vuforia
[23]	Raspberry Pi3	Temperature, humidity, light, camera	Wi-Fi	Google SpreadSheet, LINE
[24]	Arduino MEGA 2560, SIM900, DS3221	Temperature, humidity, soil moisture, light, water flow	GSM	CropWat, CLIMWAT
[25]	Raspberry Pi with GSM module	Temperature, humidity, soil moisture, rain, Venturi Injector Device	GSM	Not Specified
[26]	ESP32	Temperature, humidity, soil moisture	Wi-Fi	ThingSpeak, Blynk

[28]	Raspberry Pi	Camera	Not specified	Not specified
[30]	PIC18F4520	Soil moisture, light, pH	Not specified	Not specified
[32]	Not specified	Temperature, humidity, barometric pressure, soil moisture, pH	Not specified	Web app (Node.js, Vue.js, JavaScript)
[33]	NodeMCU ESP8266	Soil moisture	Wi-Fi	Firebase, MIT app inventor

Finally, Table III addresses the main contributions found in the literature. These contributions range from complete irrigation systems, platforms to enhance this type of systems to the use of other types of technologies within the scope of this research topic.

TABLE III. Studies main contributions.

Ref.	Main contribution
[1]	LoRa power consumption comparison
[2]	Platform for garden monitoring
[3]	Controlled environment system
[4]	Irrigation system with fuzzy logic decision support
[5]	Irrigation system integrated with home appliances
[6]	Gardening management system
[8]	Irrigation system
[9]	Greenhouse management system
[10]	Automatic irrigation robot based on point-to-point motion
[11]	Automatic drip irrigation system
[12]	Irrigation system
[13]	System for controlling electrical and electronic devices
[14]	Weather station to predict the possibility of raining
[15]	Platform for monitoring small-sizes crop
[16]	Platform for monitoring and selling crops in communities
[17]	Comparison between normal and smart irrigation with different environmental variables
[18]	Home governance system
[21]	Irrigation system
[22]	Modular grow box using augmented reality for visualization
[23]	Interactive cultivation system (paddy drone)
[24]	Irrigation system with text messaging-based support
[25]	Irrigation system with fertilizer distribution
[26]	Irrigation system with Fuzzy logic
[28]	Smart app to prevent littering problems in a botanic garden
[30]	Control system for vertical gardens
[32]	Deep learning for plant disease prediction
[33]	Irrigation system with three modes of operation

III. Methods

A methodology was followed to meet the objectives of this paper. The methods used are divided into two sections, section A which contains the research question and the consequent hypothesis. Section B, addresses the research model employed.

A. Presented study, Research question & Hypothesis

The efficiency in the management process of resources, such as water, is of paramount importance. Greater awareness of people about sustainability issues is essential, particularly in environments such as cities where this type of issue is sometimes disregarded. This can contribute to greater involvement of the population towards these problems.

1) Research questions

Research questions are fundamental to guide the research and present a clear focus of what is intended to be achieved with the research. Toward this end, two research questions have been formulated:

- How can smart gardens contribute towards cities' sustainability?
- How can low-power communications improve smart garden systems?

The first question aims to determine what the possible contributions are, in terms of sustainability, and how can that be achieved when a smart garden system is implemented within the urban setting. This translates into different types of systems whose features can help with different aspects of sustainability.

The second question delves into the communications component of the system. A fundamental part of IoT systems that is responsible for a large part of the energy costs of this type of system and whose characteristics can allow for different types of applications, something that is reflected in the general scope of this study.

2) Hypothesis

Hypothesis is defined to predict the answers to the research questions, previously defined.

Concerning the first research question, the implementation of a smart garden system must contemplate tools, such as dashboards and databases, that allow monitoring and visualization of environmental and plant conditions so that it is possible to automate some processes such as watering. With a great variety and quantity of data, a more accurate and efficient decision-making process is possible. Considering that, using different types of sensors, such as temperature, humidity, soil moisture, and sunlight, for data collection is fundamental to have a better perception of the real needs of a plant.

Regarding the second question, the use of a LPWAN such as LoRa is important due to its features that allow low energy consumption and wide-area deployment.

B. *Research Model & Instrument*

The research model employed in the development of this work follows the "Design Science Research Methodology (DSRM)" proposed by Peffers et al. in [37]. The DSRM provides a framework for design science (DS) research as well as a mental model for assessing and presenting DS research in information systems (IS). This methodology results in the development of an artifact that aims to create a solution for the problem presented in the current work. The DSRM methodology is described in sex steps:

- Identifying problems and motivation.
- Definition of objectives for a solution.
- Design and development.
- Demonstration.
- Evaluation.
- Communication.

When applying the DSRM it is possible to start with one of four different approaches. Those approaches consist of different focus points for the solution that is being developed and this results in different entry points for the development of the artifact:

- "Problem-Centered" - Entry point at stage 1;
- "Objective-Centered Solution" - Entry point at stage 2;
- "Design and Development-Centered" - Entry point at stage 3;
- "Client/Context Initiation Solution" - Entry point at stage 4.

Bearing in mind that the main reason behind this study is the problem of resources wastage, particularly in the agricultural field, which translates into a lack of sustainability, the entry point for this paper is the first stage.

The first and second stages of the process were presented provisory, in this paper. The first stage is reflected in the *Motivation* section, where the problems that exist in this field were highlighted, and motivation was given. The second stage is present in the *Presented study, Research question & Hypothesis* and *Objectives* section, where the objectives for the solution are described.

The stages that follow consist of designing and development where the solution´s architecture will be proposed and then implemented while attending to the established objectives for the artifact. After this step, the system will be demonstrated in order to test its functionalities. Following this step, the system will be evaluated according to the proposed objectives and the functionalities that resulted from those objectives. Finally, the last step consists of the communication of the work that has been developed, highlighting the importance of the artifact for the problem stated previously.

IV. CONCLUSION

The conducted research demonstrated the importance of the sustainability topic, just by analyzing the abundance of solutions proposed in the literature. The solutions are quite diversified but usually only focus on certain aspects and problems related to this type of smart garden systems. Therefore, it would be relevant to explore solutions that allow for a more agile and interoperable development, covering different types of problems related to this topic.

Despite the abundance of solutions, this study also revealed that research and development of solutions using LPWAN are not as abundant as solutions that employ Wi-Fi for example. A good starting point for the development of a solution that uses this type of network technology as it provides very interesting features that can be used to implement certain aspects that could not be implemented with other types of networks. Furthermore, vertical gardens proved to be a very efficient way of implementing this type of systems since the space for implementation can be very limited and, therefore, a vertical solution is very advantageous specially in a smart city context.

Smart garden systems proved to be an important part of the solution that aims to reduce resources wastage while making people more involved in plant cultivation and, more aware of the importance of this topic.

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