CIRC4FooD Platform: An Intelligent Management System Supporting Sustainable Urban Agriculture

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***Abstract*—An online monitoring platform for urban vegetable gardens is described. The platform has been developed within the project 'A circular economy inspired food production system' (CIRC4FooD) as a part of intelligent management system for the urban vegetable gardens, with the wider aim to engage the user and to promote and inform about circular economy and sustainable food systems. The CIRC4FooD integrated system constitutes of a garden equipped with rainwater harvesting system, composting bin and intelligent management system, namely the platform and incorporated Internet of Things (IoT) technologies: diverse sensors for soil and air parameters, for rainwater tank and for compost. The implementation of a dynamic rule engine consisting of three modules: i) environmental, ii) water tank and iii) compost, allows the users to get notification about any actions required or recommended from their side to keep the garden in proper condition, but also to assure environmental benefit (i.e., saving water resources by using harvested water, watering the garden only when real need arises, use of compost as fertilizer, etc.). In this paper the preliminary system and platform design are presented, which might be further improved followed by next steps that are scheduled within the CIRC4FooD project to test the platform in real life conditions and in different scales.**

Keywords-monitoring platform; dynamic rule engine; urban vegetable gardens, sustainability

I. Introduction

Food production poses a significant environmental burden that accounts for 10%-30% of an individual's environmental impact [1]. According to the recent report from the Food and Agriculture Organization [2], current food production systems are facing several challenges: (a) growing demand for food, driven by increasing world population and urbanization; (b) diminishing land and water resources and their declining quality; (c) climate change, and at the same time significant contribution of the agricultural sector to this phenomenon; and (d) too few investments in solutions contributing to sustainable agriculture.

Due to the environmental stress on water bodies, harmful land use practices, soil depletion and greenhouse gas emissions, the need for sustainable agriculture solutions is rapidly growing. The ever-present efforts to improve the agricultural yield with fewer resources and labor have resulted in significant innovations throughout human history. Despite those efforts, growing population rate never let the demand match the actual supply. The world population is expected to reach 9.8 billion in 2050, resulting in an increase of approximately 25% from the current figure [3].

Listed challenges, in line with destructive effect, that traditional, linear economy has on the food system, poses increasing pressure on the food system, creating urgency for resilient and sustainable food systems.

CIRC4Food project introduces a solution for local food production systems, contributing to the promotion and dissemination of sustainable food system. CIRC4Food system for food production, consists of a vegetable garden equipped with a rain water harvesting system and a composting bin. The numerous environmental, social and health benefits of urban vegetable gardens have been proven by a number of studies [4-6]. The CIRC4FooD system will be supported through an intelligent management system and will introduce user-friendly CIRC4FooD platform with user engaging functionalities, with the aim of promoting sustainable use of natural resources.

The rest of the manuscript is structured as follows. Section II describes the smart farming concept and the integrated system for application in urban vegetable gardens proposed by the CIRC4FooD project. Section III describes the system design, including user requirements collection, as well as user journey and user flow, user types and the concept behind reward system to be developed. Section IV addresses the platform design including its architecture, the rule engine and the platform view. Finally, Section V concludes on the work and outlines next steps. The work is closed by acknowledgements.

II. Smart Farming and CIRC4FooD

Smart farming, as a coupling of information, communication and control technologies in agriculture, is an idea that gains ground gradually. Smart farming is a management concept of using modern technology to increase the quantity and quality of agricultural products. The concept involves an integration of information and communication technologies into machines, sensors, actuators, and network equipment for use in agricultural production systems [7]. These applications are the driving force for the development of innovation in precision and sustainable farming.

Numerous software developments are available in the market [8-9], designed to make the farmer's tasks more efficient. However, as every particular application has specific characteristics, no "one-size fits all" technology is available. To improve the sustainability, there is a need for site specific strategies for both decision makers and farmers. Some of the specific aspects of interest of the system design and selection involve: the assessment of the techno-economic and environmental impact of an urban farming system, choice of crops and optimization of economic and environmental parameters. Obtaining the optimal design and operational plan poses a major challenge [10]. Nevertheless, the usage of all these information in the field is usually limited to the aforementioned aspects and for this reason, an inclusive and multipurpose monitoring platform is proposed, which explicitly supports the management and optimization of the performance of a vegetable garden, with special attention to compost fertilizers production and use and operation of water harvesting system contributing to sustainable urban farming systems.

In regards to that, the intelligent urban vegetable gardens in CIRC4FooD project, use technological resources that help in various stages of the production process, such as monitoring of crops, irrigation and composting process control. More precise, CIRC4FooD integrated system, as revealed in Figure 1, for implementation in urban vegetable gardens consists of the following elements: i) garden itself, ii) rain water harvesting and storing system, iii) composting bin, iv) intelligent management system integrating on-line monitoring platform and IoT technologies (including sensors).

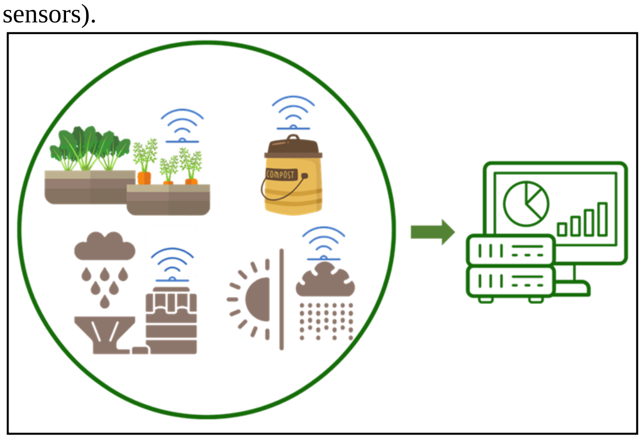

Figure 1. CIRC4FooD integrated system (own work).

The aforementioned sensors will be acquired within the purpose of the project and upon completion, the participating users will retain those sensors. More specifically, soil moisture sensors will be installed in the vegetable garden, humidity and temperature sensors inside the compost bin, as well as water level and Total Dissolved Solids (TDS) sensors inside the water tank.

III. System Design

A. User Requirements Collection

The purpose of the requirements collection is to understand the needs of the end-users and the problems they seek to resolve with the specific platform. In order to extract the requirements from the end-user's standpoint, following factors affecting the urban farming, were taken into account:

- *Weather*: Farming mainly depends on weather conditions. Farmers face great risk in growing crops, as insufficient rainfall and water supply can damage the crop or lead to a decrease in farm produce. Considering the fact, that different plants require different parameters of weather conditions, an all-purpose and simplified system – that is suitable for numerous crops – was established.
- *Lack of knowledge and skill*: Literacy is one of the most important factors affecting all the sectors. Lack of literacy results in farmers being unaware of changes occurring in the farming sector. Informing end-users about the dedicated activities, regarding the vegetable garden, motivates the interested parties to sustainable thinking.
- *Seeds/fertilizers/disease*: To grow crops of good quality, selection of seeds and appropriate knowledge about fertilizers is required. Additionally, timely and proper detection of plants affected by disease can save the farmer from loss and helps in gaining crop security. A repository with information about plants, their characteristics, possible diseases and advice on handling them will be available for users.
- *Water scarcity:* A more efficient irrigation management, focused on reducing the capacities of water applied and therefore optimizing the conservation of irrigation water is conceivable through the platform, that helps the end-user to plan the irrigation activities.
- *Promotion of circularity in food production:* The shift from a linear model to a circular model can meaningfully decrease the negative burdens on the environment and contribute to reestablishing biodiversity and natural resources. With this aim, the presented platform can play a relevant role in setting the paths of this transition, nurturing the shift towards a more sustainable agriculture.

Based on the aforementioned factors and through a dedicated questionnaire that was conducted during the CIRC4FooD project by e-Trikala, which is the responsible partner for the implementation of the urban vegetable gardens in the city of Trikala during the CIRC4FooD project, user requirements were collected, which are focused on i) standardized data (sensors data, weather data, user or hardcoded data); and ii) functional requirements (personalization, authentication, authorization, scalability, usability, localization, etc.).

B. User Journey and User Flow

User Journey refers to the scenarios in which the user interacts with the product. This visual representation is commonly created as a timeline of actions or steps by a facilitator, built up on feedback collected methodically (via observations, interviews, focus groups, etc.). As a result, the technique's main function is to assume and demonstrate the current and possible way in which the user can interact with

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the process. User Journeys deal with emotions, pain points, and motivations of the end-users [11]. For this aim, the establishment started with the completion of a user journey map. The developed map is a visualization of the step by step experience as the user goes through the platform, following the diagram as shown in Figure 2.

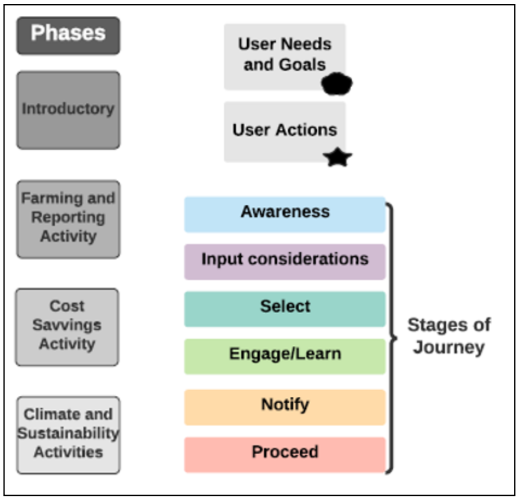

Figure 2. Concept of User Journey (own work).

User Flow refers to the process in which user takes advantage of the complex routes through a series of templates, designed for a product to accomplish their goal. It is created to predict and show the possible routes, through which the user interacts with the product. User Flows are usually depicted by flow charts, they are a set of steps taken by a user to achieve a goal using a digital product. Rather than demonstrating, how the users are supposed to feel, a User Flow is the breakdown of the actual user interface. Designing how a user interacts with a product is a key step in figuring out, where the issues may arise in task flows [12].

Having finalized the User Journey and the User Flow, user types were selected and ways to accomplish user engagement with maximum impact were identified.

C. *User Types and Reward System*

To assure comprehensive and effective knowledge acquisition, users of the platform are assigned into one of the following user types: novice, advanced beginner, competent, experienced. The assignment is based on the self-assessment performed by the user based on the information provided for each level of expertise and adapted from [13] for the needs of the platform.

Reward system will be implemented based on the user engagement, allowing the users that are most active to be upgraded to higher levels of expertise as they gain knowledge and know-how.

IV. Platform Design

A. *Architecture*

The architecture of the web platform follows the principles of a MERN full-stack development. MERN stack is a JavaScript stack, that is used for easier and faster deployment of full-stack web applications. MERN Stack comprises of 4 technologies namely: MongoDB, Express, React and Node.js and it is designed to make the development process smoother and easier as depicted in Figure 3.

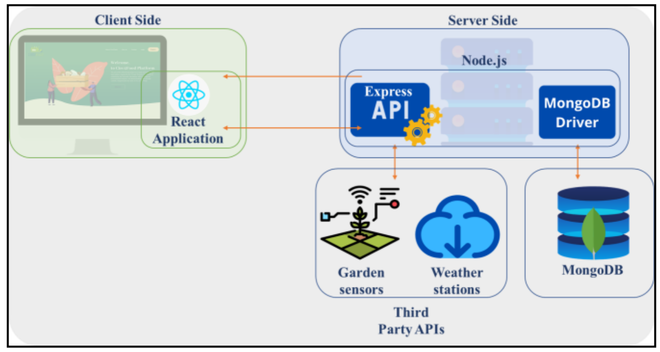

Figure 3. Architecture of the CIRC4FooD platform (own work).

MongoDB is an open-source document database built on a horizontal scale-out architecture that uses a flexible schema for storing data [14]. In the CIRC4FooD platform, MongoDB is used to store as object-collections information related to the system users, their integrated system and the notifications extracted from the rule-engine.

Express is a prebuilt Node.js framework that can help creating server-side web applications and APIs faster and smarter. Simplicity, minimalism, flexibility and scalability are some of its characteristics, and since it is made in Node.js itself, it inherited its performance as well.

On the client-side part there is React.js. React is an open-source, component-based front-end library, responsible only for the view layer of the application. It is maintained by Facebook. Using functional programming, hooks and JSX, React designs simple views for each state in the application, and will efficiently update and render just the right component when the data changes. As a front-end framework, React communicates with the back-end by making API calls on the endpoints created by Express.

The last technology is Node.js. Node is an open source development platform for executing JavaScript code server-side. It is intended to run on a dedicated HTTP server and to employ a single thread with one process at a time [15]. Node.js applications are event-based and run asynchronously. In the CIRC4FooD platform, Node.js has a central role as it is the one responsible for serving the client-side code, managing the Express APIs and communicating with the MongoDB database. Moreover, Node.js fetches data from a third party API related to the current values of each sensor placed on the gardens and stores them to the proper collections in the Mongo database. Furthermore, it handles the authentication and role system for the users as long as the reward system and the dynamic rule-engine, that creates the proper notifications for the platform users. More about the rule-engine and the reward system will be presented in the following paragraphs.

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B. Dynamic Rule Engine

The process of preparing a rule base in CIRC4FooD can be divided into several consecutive steps that are presented in Figure 4 below, wherein several layers are created: data collection from several sensors (as described in Figure 1), system modelling and rule selection, environmental sustainability, deployment of rules and also system optimization. The rules guiding the dynamic rule engine were constructed with two main purposes: i) to promote sustainability and natural resource preservation and ii) maximize user engagement. In order to assure user engagement, the number of received notifications, but also their exact content is adjusted to the level of experience of the user. The higher the level of experience, the higher number of notifications user gets, while their content becomes less explanatory and more informative. This is illustrated well with the examples of notifications presented in Table 1.

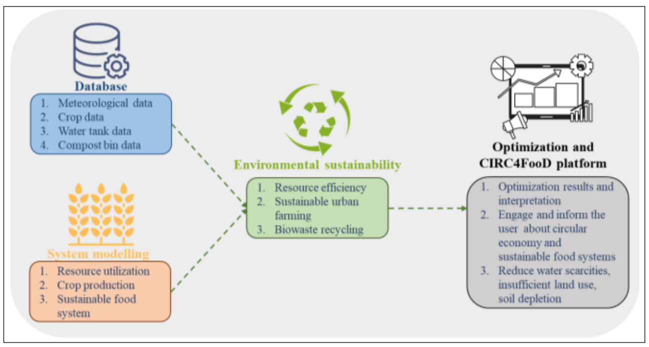

Figure 4. Outline of the process of prepearation of the rule base in CIRC4FooD (own work).

TABLE I. EXAMPLES OF NOTIFICATIONS FOR FOUR USER TYPES

Condition description	**User Type**			
	Novice	***Advanced Beginner***	***Competent***	***Experienced***
Air humidity < 30% and soil moisture <20%	The soil moisture levels are below optimal and air humidity is low. Consider watering your crops.	Crops in conditions like today's will most probably need water.	Air humidity today will be low and soil moisture readings indicate that your crops need water.	Air humidity < 30% and soil moisture <20%
Water tank level: full	N/A	Your water tank is full, now is the time to save natural water resources.	Water tank is full.	Water tank is full.
Compost moisture >60 %	Your pile moisture levels are above the optimum. To keep them within the optimal range mix in some newspaper strips, dry wood chips or pieces of cardboard.	Your compost is too wet. Mix in newspaper strips, dry wood chips or pieces of cardboard.	The optimal levels of moisture range between 40 to 60 %. Today the moisture level is >60 %. Take appropriate actions!	Compost moisture > 60 %

The rule engine consists of three modules: i) environment, ii) water tank and iii) compost. The module environment gathers rules related to the environmental parameters influencing plant growth, with special attention to those related to watering. Parameters taken into consideration in this module are following: soil moisture, air humidity, likelihood of precipitation, temperature, light intensity and wind speed.

Module water tank describes the rules associated with water level and TDS amount in the water tank, but also the water level in combination with probability of precipitation and soil moisture, to assure that water is used only when a need arises.

Module compost is built to support the composting bin notifications in relation to compost temperature and compost moisture. Compost temperature and compost moisture are two critical parameters for the process of compost production. Compost temperature is additionally a crucial parameter in compost monitoring [16]. Monitoring temperature evolution along time provides critical information about the course of composting and assures safety of the produced material (eliminating the risk of microbial contamination) [17], as well as safety of the process itself (avoiding fire hazard).

The conditions are assigned impact values based on the literature research and the CIRC4Food aspirations, namely user engagement, awareness raising and saving natural resources, especially water. The impact values affect the notifications scheme of the rule engine, which is build on threshold values. The user receives notification only, if the threshold value is equal or surpassed by the impact value. The threshold value (and therefore whether or not the notification will be received) is determined by the user type. The dynamic rule engine is designed in such way, that additional rules can be implemented, if need arises.

C. CIRC4FooD Platform view

The front-end application exposes to the user a pleasant and interactive interface, through which the user can access all the services exposed by the back-end application. The CIRC4FooD interface is responsive, so the user experience on the platform is of high-quality regardless of the device used (laptop, PC, table or phone). In addition, CIRC4FooD platform allows end-users to explore and analyse agricultural and weather data with zero-programming efforts. The User Interface (UI) exploits concepts that the user is familiar with and facilitates further understanding (through, e.g., plots, studies, sensor device, etc.), as defined in the data model and the rule engine. The initial UI is depicted in Figure 5, Figure 6 and Figure 7.

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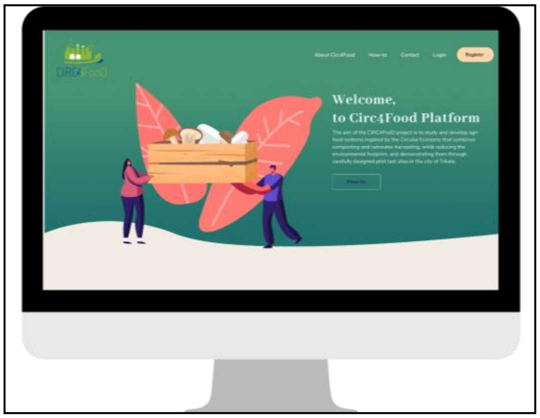

Figure 5. Welcome Page of the CIRC4FooD Platform (own work).

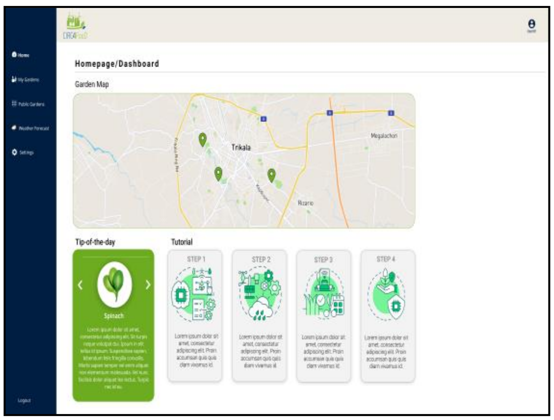

Figure 6. Homepage/Dashboard view (own work).

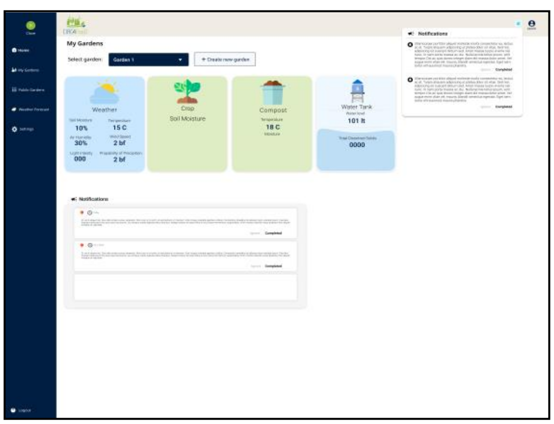

Figure 7. My gardens page (own work).

The UI is still a work in progress, aiming to achieve an intuitive visualization, that will depict the requirements of the end-users in order to contribute to the promotion of the sustainable urban agriculture.

V. CONCLUSION

The CIRC4FooD platform is created to enable efficient management of urban vegetable gardens. In parallel, by engaging the user at different levels, it has the ambition to offer educational and awareness raising advantage. In this paper we present the ongoing work related to the platform development describing system and platform design.

CIRC4FooD platform will be tested in real life settings in the coming months. The demonstration will last around 6 months in the city of Trikala in Greece and will start once the complete CIRC4FooD system is set up. Demonstrations will be performed in private gardens belonging to citizens of Trikala, in public, popular spaces of the city and in several schools. The testing phase will be accompanied by a series of seminars of informative and education character aimed at the users of the CIRC4FooD platform. It is expected that as a results of demonstration activities and received feedback, some features of the platform might be subject to change. Additionally, user reward system will be implemented and a repository for the users with information about how to use the platform and facts about the plants (e.g., preferences and common diseases) will be developed.

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