# Deploying Smart Community Composting in Estrela UNESCO Global Geopark: A Mobile App Approach

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**Abstract**

Community composting is a key pillar of circular economy and sustainable food production. This paper presents the development of a regional composting network in Estrela UNESCO Global Geopark, using mobile technologies and geographic information systems. This design science research project presents the community composting model and the instantiation of a mobile solution layer. For theory, this paper reveals the concept of smart community composting inspired by the 5.0 movement expanding in society, cities, and industries. For practice, this work presents a mobile information system tailored for UNESCO Geoparks and their recently created GEOFood brand to promote sustainable production practices.

**Keywords:** Smart Region, Smart Community Composting, Geopark, Circular Economy.

## 1. Introduction

Circular economy (CE) is mobilising the information systems (IS) community [37]. This claim is supported by the critical role of information to achieve transparency in material flows, since "*isolated windows of data availability only lead to local optimization of process efficiency for individual actors but fail at realising CE's full potential*" [37]. Digital transformation and creating networks connecting different stakeholders of sustainable supply chains will be a priority [6].

The food supply chain is one of the most serious candidates for circular practices. Over 30% of the food is wasted, and production will need to increase by 60% in 2050 [15]. Composting is a possible solution to reduce waste while simultaneously improving the soil and society's response to climate changes [3], [9]. This practice can be adopted at homes but also in specific communities [22].

Digital transformation in industry and cities are shifting to the 5.0 era [27]. The European Commission presented the priorities for Industry 5.0 in 2021: sustainability, human-centric development, and resilience with a "*focus from shareholder to stakeholder value, with benefits for all concerned*" [12]. This vision is inspired in the Society 5.0 proposed by Japan and also aligned with the recent City 5.0 concept defined by [27] as "*a liveable city that is (re)modelled with the aim of eliminating restrictions for its citizens by using digitalization for the provision of public goods and services*". Also, agriculture is shifting to digitalisation for sustainability, as detailed in the report presented by the Food and Agriculture Organization of the United Nations [29]. Technologies like the Internet of Things (IoT), cloud, and mobile solutions may be adopted in individual smart composting systems [2], [5], [21]. However, there is a lack of digital solutions for smart composting at a regional scale. Smart community composting is the challenge addressed in this paper.

This research started in cooperation with Estrela UNESCO Global Geopark (Estrela Geopark) [34]. UNESCO recognised this region's geological relevance in 2020, and their association's strategy puts sustainability at the top of the priorities. They aim to incorporate a circular economy in local food production (primarily small and medium-size companies) supported by information technologies (IT). Accordingly, the following research objective was formulated: (RO) *deploy a smart community composting platform to support Estrela Geopark's circular economy*.

The rest of this paper is organised as follows. Section 2 presents the research approach and the Estrela Geopark context. Next, background literature on CE, IS, and smart composting is presented. Section 4 details the design, development, and evaluation of the smart community composting platform. Subsequently, we summarise the conclusions, limitations, and future work opportunities.

## 2. Research Approach

Design Science Research (DSR) [14], [18] is the selected research approach. The resulting IT artefact seeks to assist Estrela Geopark in adopting circular economy practices at a regional level. Fig. 1 summarises our research according to the DSR grid proposed by [4]: *problem description, input knowledge, research process, key concepts, solution description, and output knowledge*.

| | | |
|---|---|---|
| *problem*<br><br>A digital platform is necessary to deploy community composting. Existing proposals were not made for regional scale. | *research process*<br><br>Steps of problem formulation, design and development, evaluation, and communication [25]. There are also relevant standards to improve research quality [26]. | *solution description*<br><br>IT artefact with web/mobile interface. IoT Infrastructure for smart composters. |
| *input knowledge*<br><br>GEOFood; Smart Regions; Smart composting systems. | *concepts*<br><br>Information systems; Circular economy; Composting; Geographic Information Systems. | *output knowledge*<br><br>Design requirements and a guiding model for community composting in smart regions. |

**Fig. 1:** DSR Grid for the Development of Smart Community Composting.

This paper details an initial cycle of our DSR project focusing the mobile app design. Therefore, the smart community composting system's design, development, and deployment are still in the pilot project stage, evolving under supervised conditions.

### 2.1. Design Science Research Setting

Estrela Geopark is a territory in the Iberian central region with geological heritage, "*a rich biodiversity and long history of human presence with strong cultural and economic links to the mountain*" [34]. Geoparks recently launched the GEOFood brand worldwide to distinguish and help producers in protected regions [33]. The GEOFood manifesto fosters sustainability (maximising local materials; minimising transport impact), cooperation, and preservation of regional food heritage.

Fig. 2 presents the Estrela Geopark territory and the endogenous food production.

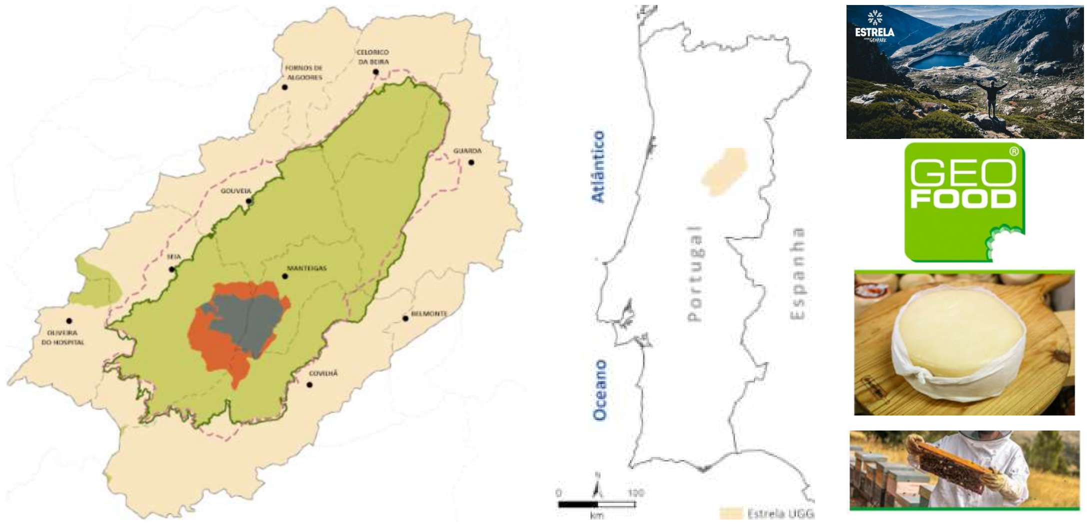


**Fig. 2.** Estrela UNESCO Global Geopark Territory.

Estrela Geopark's territory is vast: 2216 km$^2$ and nine municipalities (on the left of Fig. 2). Their association wants to incorporate community composting as part of their overall sustainable strategy for local food production (according to GEOFood regulations). The GEOFood logo (registered trademark by the Norwegian - Magma Geopark) and examples of typical products in the region are included on the right of Fig. 2.

Composting organic material (e.g., food scrap, weeds, dry leaves, or fruits) is not yet disseminated in the community. The transformation of food waste compost can reduce their footprint while informing the population about this critical priority for the coming years. Estrela Geopark also wishes to strengthen the links between different zones in the territory. They are planning to create a network of (1) urban food waste producers and (2) rural food waste recyclers (the local food producers).

At this research stage, Estrela Geopark is interested in modelling the circular economy network for smart composting and deploying the mobile IT solution that supports their circular economy strategy. The following section presents key literature on circular economy, information systems, and smart composting.

## 3. Bibliometric Analysis and Background Literature

The selection of papers included in this section was made in Web of Science (WoS) and Scopus.

We started with a bibliometric analysis using specific keywords and identified key clusters and concepts with the VOSViewer tool [10]. Subsequently, we have screened related work to identify trends in this line of research.

### 3.1. Information Systems for Circular Economy

Fig. 3 presents the results of a search in WoS (all fields: 41 results) and Scopus (title, abstract, and keywords; 88 results) using the keyword combination "information systems" + "circular economy".

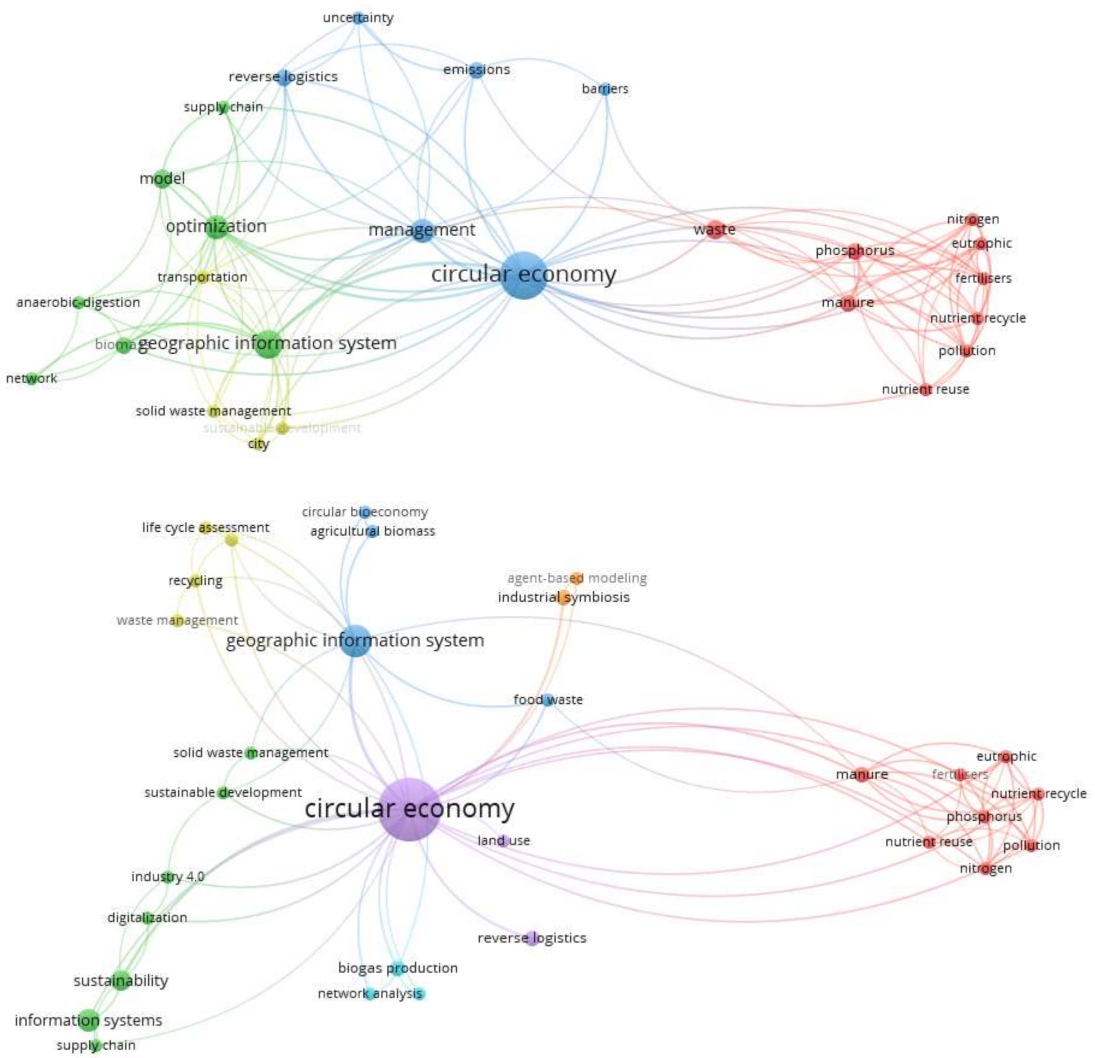


**Fig. 3.** Information Systems and Circular Economy: Bibliometric Analysis.

WoS (at the top) presents four main clusters: the red cluster (on the right) associated with specific products (e.g., nitrogen, fertilisers, nutrients); the central blue cluster for circular economy and the close relation with managerial aspects, reverse logistics, barriers, uncertainty, and emissions; the more "IS-related" green cluster (e.g., model, network, supply chain); and the yellow cluster including transportation and urban development (e.g., solid waste, city). Scopus reveals more clusters, with the red (products, nutrients) and green (IS-related) aligned with WoS, but also includes specific clusters of papers about agriculture (blue cluster, aggregating geographic information systems, food waste, biomass). In both cases, it is clear (1) the critical role of geographic information systems in circular economy development, (2) the need to create networks within the supply chain, and (3) the significance of food systems in circular economy developments.

Circular economy has entered the IS agenda. The recent paper published by [37] with the purpose to mobilise the IS community for this "grand challenge", reveals two important lines for future research: "[f]*irst, in consideration of recent advances in tracking technologies, we invite discussions on the issue of representational faithfulness of complex product systems in circular material flows. Second, in acknowledgement of the dynamic and often unpredictable nature of circular material flows, we invite discussions on issues of data sharing in large and complex social systems"*. An example of a study in this area is presented by [35] for industrial parks' perspective. The main IS elements are (1) the information about companies in the network, (2) material flow, (3) key flow traces, (4) regulations and standards, and (5) industrial symbiosis [35]. Another recent example using geographic information systems is the web-based interface developed for solid waste management in England [24].

Real-time monitoring of supply chains will enable a clearer understanding of material flows [37], leading to more efficient control, reducing costs and waste, and (when possible) re-introducing them back into the chain. Product traceability is currently a significant challenge that can be ensured through information systems [13], [31]. In addition to improving communication between stakeholders [36], information systems bring the links of circularity and the ability to balance the supply-demand relation [30].

Some authors have focused on agriculture and food supply chains. The study conducted by [28] in Spain concludes that it is viable to use food waste (collected in distribution and retail) for animal feed. Different organic wastes can be used for producing compost that is important for fertilisation, such as wineries [17]. Blockchain is a possible solution to test in the creation of circular economy networks [31], but digitalisation in general, using different technologies (e.g., IoT, big data, data analytics) can contribute to creating a smarter circular economy [16]. Information is crucial to (1) monitor the production of waste, (2) support the creation of networks of stakeholders to reuse waste, as happens in the case of compost, and (3) explore the potential of data to optimise the process.

The next section details the potential of digital transformation for the issue of food waste and smart composting systems.

### 3.2. Smart Composting

Geographic information systems have an important role in composting digitalisation, but there are other opportunities, as shown in Fig. 4.

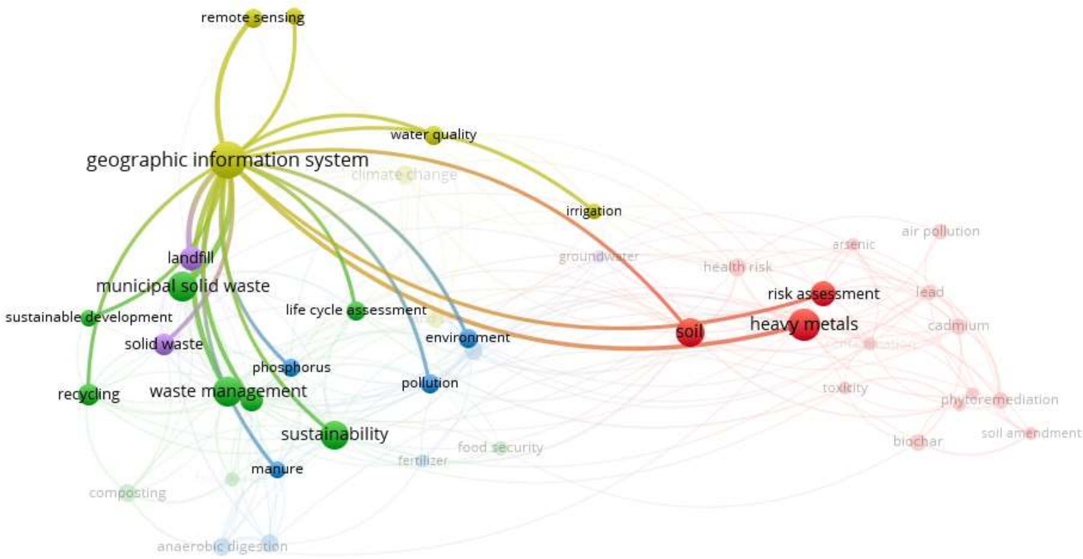


**Fig. 4.** Information Systems and Composting: Bibliometric Analysis in Scopus.

Only 20 papers were found in Scopus using the keyword “smart compost”, and one in WoS. The latter is presented by [23], creating an Arduino-based prototype to monitor temperature, humidity, moisture, and gases. Therefore, we searched all fields in Scopus using the keyword (compost OR composting) AND “information system”, returning 1724 hits represented in Fig. 4. The yellow cluster highlighted in the figure reveals the importance of remote sensing. An interesting example using wireless sensor networks is presented by [5], illustrating the details of sensing temperature, moisture, and communication infrastructure.

Sensing devices can be used for on-farm composting [7], and several studies present prototypes for smart composting systems. For example, the smart composting system built by [2] using an Arduino or the IoT-based solution created by [32]. Another example of a smart composting machine is presented by [11], including a mobile app for real-time system parameter management. However, these studies are for a single composting unit, and when multiple composting units exist, it is necessary to add the potential of the cloud [21].

Composting is also evolving to a community scale, aiming at more sustainable consumption. New technologies can contribute to this goal, as presented by the study of [8]. Community composting can be implemented in urban areas [9], and its benefits are already reported in the literature, for example, the study made in the city of Chicago [22]. Rural composting is also possible [20]. However, information systems development for urban and regional areas (e.g., UNESCO Global Geoparks) with multiple composting sites is still understudied.

## 4. Results

This section details the DSR phases of design (4.1.), development and instantiation (4.2.), and evaluation (4.3) made by researchers and practitioners.

### 4.1. Smart Community Composting Network

The goal-oriented requirement language (GRL) diagram in Fig. 5 illustrates the main goals of different composting actors. GRL is a modelling language used to describe the various stakeholders' intentions, goals, and non-functional requirements in a system [1].

A GRL diagram includes elements interconnected by various types of links (e.g., contribution, correlation, decomposition, or dependency), namely: (1) *goals* (⬭); (2) *soft-goals* (⬭), which differ from the former due to the lack of a precise classification; (3) *tasks* (⬡), which operationalise goals and soft-goals; (4) *beliefs* (⬭), which represent design rationales; and (5) *resources* (▭), which must be available to other elements [1]. The system and its stakeholders are represented in the form of *actors* (○).

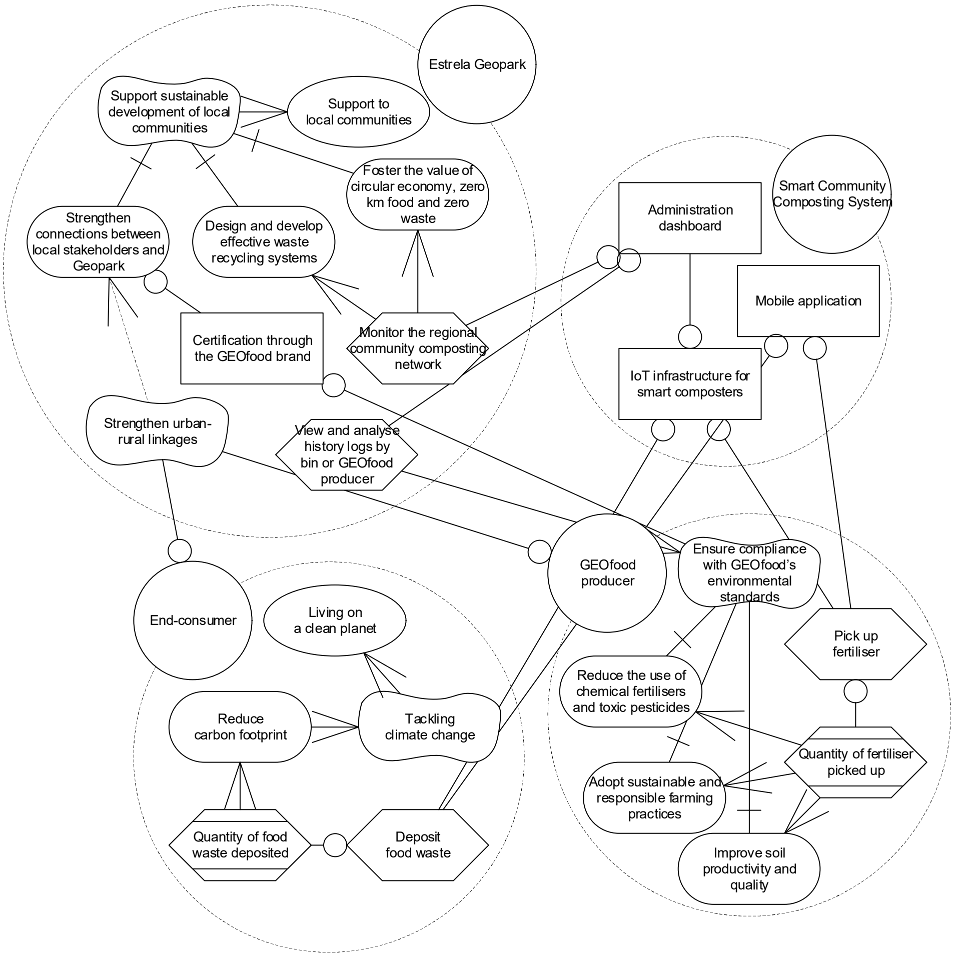


**Fig. 5.** Smart Community Composting Network at Estrela Geopark: Goal Model.

Four actors are represented in Fig. 5. Estrela Geopark (on the top) has three main goals and two soft-goals that need both consumers' and producers' adherence to be achieved. The smart composting system provides support to the network tasks (e.g., collecting food waste, monitoring) using physical (e.g., IoT-based compost unit) and digital layers (mobile/web platform). The logistics will be mainly the responsibility of the system users, from the deposit of food waste to the fertiliser collection, except for the maintenance of the compost heaps and compost bins that municipal workers will handle. Fig. 6 summarises the main interactions between end-consumers and producers.

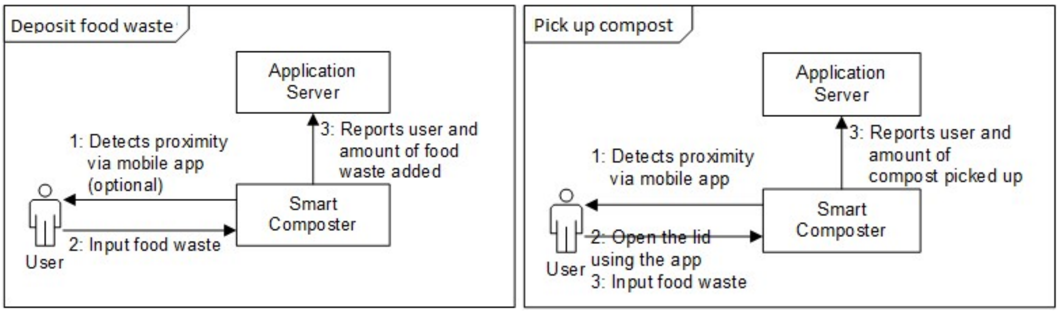


**Fig. 6.** Smart Community Composting Interaction: End-Users and GEOFood producers.

Enabling circular economy in community composting is possible via information systems. The following section details the development and instantiation planned for the region.

### 4.2. Artefact Development and Instantiation

The smart community composting system has three key components: (1) IoT infrastructure for smart composters; (2) web platform for Estrela Geopark supervision; and (3) application for mobile devices.

The IoT infrastructure consists of an extended network of smart composters planned for various points in the Estrela Geopark territory's urban centres. Each smart composter is IoT-enabled, allowing monitoring the compost heap size and the main parameters characterising the composting process's state (namely, temperature, humidity, and methane) and access control to the bin content (through an electromagnetic lock attached to the bin lid). The smart composters are connected via a Low Power Wide Area Network (LPWAN) [19] to communicate with the application server.

Fig. 7 displays the real-scale prototype of the smart composter currently being tested.

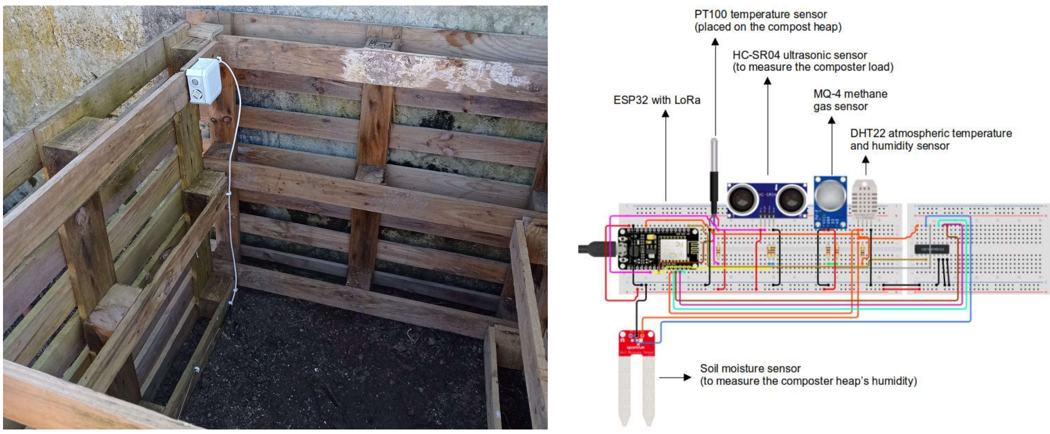


**Fig. 7.** Smart Community Composter Unit and IoT Diagram

The physical part of each composter (top removed to show the interior) maximises the use of local materials (e.g., wood). It is equipped with an LPWAN device using LoRa [19] and sensors to monitor relevant composting process parameters (circuit represented on the right).

The physical layer is complemented with a digital one. The web platform will allow

Estrela Geopark's team to monitor the smart composter network's real-time status. Fig. 8 presents the administration dashboard graphical user interface (GUI).


**Fig. 8.** Administration Dashboard GUI.

On the left side of Fig. 8, the 3D replica of the composting unit presents the amount of fertiliser. It is also possible to identify the smart composting network devices' location, the parameters, warnings (e.g., composter waiting for pickup), and activity log.

The mobile application is designed for GEOFood producers and end-consumers of the food supply chain to interact with the community composting system. The app is optional for the end-consumer actor (may assist in locating composting bins but is unnecessary for depositing food waste - unlocked). The GUIs for the mobile app are detailed in Fig. 9.


**Fig. 9.** Mobile Application GUI's High-Fidelity Prototypes.

The first image (Fig. 9a) presents the system access and registration. The mobile app integrates Google and Facebook authorisation mechanisms to facilitate both tasks. Some personal data will be required from the users, namely, name, date of birth, the municipality where they live, and their role in the system (Fig. 9b). The producer's database (network of companies adopting the GEOFood brand) is restricted and managed by Estrela Geopark.

The mobile app identifies the nearest composter and suggests the route according to the user's location (Fig. 9c - 9e). Identifying the nearest available composter will depend on the user's role. On the end-consumer side, the suggested route points to the nearest composter that is not yet full of material nor at a final stage of the composting process (the composting process takes a few weeks) (Fig. 9g). On the producer side, the app will point to the composter that contains natural fertiliser resulting from completing the composting process, ready for pick up (Fig. 9f). We assume that the user will only play one of the application roles (end-consumers are more associated with urban areas since, according to the association experts, local farmers usually recycle their food waste).

To ensure the quality of the compost produced, we have equipped the system with mechanisms that prevent users from disturbing the process (by not allowing the lid of the bin to be opened after detecting that it is complete) and redirecting them to the nearest available composter (Fig. 9h).

The app also enables users to view metrics related to their interactions with the community composting system. On the one hand, the end-consumer will see how much food waste is re-introduced into the food supply chain and to what extent this contributes to reducing their carbon footprint (Fig. 9i). On the other hand, the GEOFood producer will see the amount of fertiliser introduced into his production and check if they meet the environmental standards to keep GEOFood's certification.

### 4.3. Evaluation

This DSR conducted in cooperation with Estrela Geopark received positive feedback for the mobile app approach. According to the association experts, the system will generate valuable data to quantify the amount of fertiliser each GEOFood producer picks up to support Estrela Geopark goals. Moreover, the data could be used to conduct quantitative studies to portray the users' behaviours regarding community composting and, finally, understand how community composting can foster territorial cohesion between urban and rural spaces. Data will be handed in compliance with European Commission directives relating to data protection and privacy.

Estrela Geopark will be capable of monitoring the status of its network of smart composters spread throughout the region in real-time. Additionally, the dashboard allows the analysis of the usage records per composter, producer, food supply chain (e.g., farmers, cheese producers), and municipality. Remote supervision is necessary to enable readjustment of the smart composters network (e.g., best location) and promote awareness-raising actions in cities less aware of environmentally friendly practices. Incorporating food waste in regional supply chains can improve soil productivity and quality and avoid chemical and toxic fertilisers and pesticides.

Although this instantiation of the community composting system is still evolving, the team found the results promising. Estrela Geopark acquired an innovative solution for a community composting network, integrating multiple requirements of the GEOfood brand. The proposed solution can provide evidence of compliance with GEOfood goals by the local food producers. Moreover, the final consumer will have an additional tool to reduce the environmental footprint and contribute to the local economy. Information systems will play an essential role for circular economy development, (1) balancing the needs of material producers and consumers, (2) improving (mobile) stakeholders' communication, and (3) ensuring more precise quantification of materials reuse.

There are also challenges in the selected approach for smart community composting. First, the mobile application opens the composter when a user is close to it (i.e., ~1 to 2 meters to allow some error in the measurement). The mobile device requires GPS location and Internet access for proper operation, which is a current system limitation. Second, the composter structure is made of wood, which is an advantage and more vulnerable to vandalism. Future work must improve the locking system when the compost unit is full and waiting for pick up (unlocked by authorised GEOFood producers). Third, the system needs maintenance that needs to be made by municipality staff. This is not so problematic because the municipalities are the main associates of Estrela Geopark. However, specific training (e.g., replacing a damaged sensor) and procedures (e.g., routinely check if the composter is properly used) will be needed.

## 5. Conclusion

This paper presented the development of smart community composting in Estrela Geopark, using a mobile app approach. The research process adopted the design science research paradigm [14], [18] and aimed to incorporate circular economy practices in a UNESCO territory with geological significance. Furthermore, the technology layers explored the potential of IoT and mobile systems to deploy an infrastructure connecting (1) urban areas producing food waste, (2) rural areas incorporating compost in food production, and (3) the recently created GEOFood brand [33] for sustainable food and agriculture.

This work also has limitations that must be stated. First, although Estrela Geopark association confirmed the robustness and suitability of the developed artefacts for their strategy, the system is not yet deployed in the entire region. A real-scale prototype is under evaluation before replicating the composting devices in the nine municipalities. Second, transferability to other Geoparks adopting the GEOFood brand is also unconfirmed at this stage. Moreover, each Geopark presents a different combination of towns/cities and rural areas. Only some of them may share the exact characteristics of Estrela Geopark, with a wide area of urban users and the production of endogenous food products that incorporate compost in their lifecycle. Currently, there are 161 Geoparks in 44 countries, and 24 are integrating the GEOFood initiative. Third, producers' adherence to the smart composting system can be ensured via GEOFood requirements to use the brand and economic incentives for compost. However, urban users composting practices are only now beginning in some regions like Estrela Geopark. Some municipalities are already supporting home composting (which may simplify the transition to community composting by users more sensitive to environmental-friendly behaviours). However, many end-users will need more time to adhere to community composting. The experts participating in this project believe that the system may contribute to this goal, showing the importance of circular economy to the entire region and simplifying compost pick up even when home composting is not common.

Important opportunities for future work are also identified. First, departing from the DSR limitations found, it will be necessary to scale up the municipality level platform. A gradual deployment to increase region awareness for circular economy, simultaneously supporting their endogenous food production and external image, is considered the best approach by Estrela Geopark. Second, data analytics and artificial intelligence capabilities are still immature. The data collected can be used to create a circular economy index for the region and identify patterns of compost production in each area of the Geopark. Third, smart community composting is only a part of the circular economy potential. Information systems will be essential to improve sustainability in smart regions, increasing cohesion between urban and rural areas while contributing to the competitiveness of the local economy. The next step of this research will refine the composter unit and expand the deployment in one of the municipalities that belong to Estrela Geopark. Several DSR iterations will be necessary to deliver an effective solution to the entire region.

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