ICIS 2022 Proceedings

Digitization for the Next Generation

Dec 12th, 12:00 AM

Advancing the Smart Region Digital Twin: The Case of UNESCO GEOfood

Jose Monteiro
University of Coimbra, jose.monteiro@student.uc.pt

João Barata
University of Coimbra, barata@dei.uc.pt

Advancing the Smart Region Digital Twin: The Case of UNESCO GEOfood

Short Paper

José Monteiro
University of Coimbra, CISUC, DEI
Coimbra, Portugal
jose.monteiro@student.uc.pt

João Barata
University of Coimbra, CISUC, DEI
Coimbra, Portugal
barata@dei.uc.pt

Abstract

Organic food waste recycling is one of the final frontiers for a sustainable food lifecycle. Digital twins may be helpful to close the loop in more advanced food supply chains, but there is a lack of guidelines on how to adopt this emerging technology in community composting. This paper presents a digital twin-driven design to address this need in a UNESCO-protected region with geological relevance (Geopark). The design science research project offers the foundations for creating intelligent composting networks supported by digital technologies. Six initial design principles are suggested for developing digital twins at a regional level. This study contributes to the deployment of layered digital twins in sustainable regional development. Moreover, our proposal assists the integration of local food producers in regional food supply chains and increases the impact of sustainability brands like GEOfood.

Keywords: Digital Twin, Smart Region, UNESCO Global Geopark, GEOfood, Community Composting

Introduction

Sustainable food production is one of the significant challenges for the coming decades (Bradford et al. 2019). However, it is surprising that over 30% of the population is lost in modern food supply chains (Bradford et al. 2019; Liu et al. 2021). The combination of circular economy and advanced information technologies may contribute to change this scenario: (1) reducing (e.g., via energy consumption or raw materials), and (2) recycling or reusing food waste (Dantas et al. 2021). The latter is usually associated with composting: organics decomposition into smaller compounds used to fertilize plants. Moreover, composting can be done at home or at the community level (e.g., in cities, towns, or other specific regions) (Bradford et al. 2019). Community composting uses public areas to share composting bins with the local population.

Digital transformation in agriculture (Agriculture 4.0) promises to change food supply chains (Liu et al. 2021). According to Smetana et al. (2021), "*cyber-physical nature of modern food is a key for the engineering of more nutritious and sustainable paths for novel food systems*". These authors also point to the critical role of digital twins in food supply chains (especially in factories). This "twin" is "*an integrated multiphysics, multiscale, probabilistic simulation of a complex product, which functions to mirror the life of its corresponding twin*" (Glaessgen and Stargel 2012). Usually presented as a three-dimensional replica of physical objects, digital twins use real-time data obtained from sensors and explore artificial intelligence's potential to learn from operational data, the environment, and other similar twins: the "fleet". Recent examples in food supply chains include monitoring crop growth or environmental conditions throughout the stages of sourcing, producing, and delivering food (Verdouw et al. 2021). However, the adoption of digital twins in the "final frontier" of organics recycling in specific communities is still understudied (Semeraro et al. 2021).

This short paper seeks to establish the foundations for a smart region digital twin. The scope of the research is limited to the local food supply chain of regional products and the guidelines of the newly GEOfood brand. We detail the roadmap that will be carried out to develop smart region digital twins, as well as present the main results obtained and lessons learned, established in the form of design principles. Our first artifact instantiation focuses on community composting to close the supply chain loop.

The remainder of this paper is presented as follows. The next section revises the literature on food supply chains, and digital twins in Agriculture 4.0. The following section introduces the research context and approach: design science research (Hevner et al. 2004). The project results are then detailed, followed by the discussion. Six design principles are suggested to deploy digital twins with a layered architecture at a regional scale. The paper concludes by summarizing the contribution, limitations, and opportunities for future work.

Background

Food Supply Chain in Geoparks

Information technologies have enabled new traceability forms in food supply chains, improving communication between different stakeholders of food production (Smetana et al. 2021). Comprehensive architectures and conceptual models have been recently proposed to foster cooperation between farmers and service providers, transforming this traditional sector of the economy into a cyber-physical system (Smetana et al. 2021). Creating "*sustainable paths for novel food systems*" (Smetana et al. 2021) is the priority, virtualizing all possible systems with the Internet of Things (IoT) until reaching the end customer.

Sustainability is also a priority for UNESCO Global Geoparks (Geoparks) in their local supply chain of endogenous products (Vieira et al. 2020). The GEOfood initiative led by Norway, Denmark, Finland, and Iceland aims to strengthen local food traditions. Their supply chains are pressured to reduce waste, maximize the use or reuse of local resources, ensure "zero-kilometer food products", and make responsible use of resources. Therefore, new systems are necessary to support local producers in organics recycling and ensure compliance with the GEOfood manifesto (Magma Geopark 2020).

Digital twins may contribute to the efficiency of food supply chains, and Geoparks are appealing for deploying pilot projects in digital transformation. However, despite the potential of digital transformation for different food supply chain steps, namely, sourcing, producing, and delivering (Verdouw et al. 2021), it is unclear how information technology and cyber-physical systems operate in the final stages of the food lifecycle: waste reduction and recycling.

Digital Twin and Cyber-Physical System in Agriculture 4.0

Digital transformation in agriculture is evolving alongside Industry 4.0 technologies and practices: big data, IoT, robotics, cloud, and end-to-end digital integration (Lezoche et al. 2020; Liu et al. 2021). Supply chain efficiency is one of the significant challenges of this transformation (Liu et al. 2021). More advanced systems create virtual representations of modern farms supported by IoT. Therefore, digital twins are essential to agricultural development.

The popularity of digital twins is close related to advanced made by DARPA and NASA for air force vehicles (Glaessgen and Stargel 2012). It is on the agenda of global companies such as General Electric (GE 2016), and major airplane producers are already creating intelligent "digital mirrors" for their projects. The topic captured the attention of researchers, and there are important guidelines available to design digital twins, namely (Tao et al. 2019): (1) create virtual representations; (2) use data to support design decision-making; (3) simulate the product behavior; (4) control the physical product according to the desired performance; (5) establish secure connections between the physical and digital layers; and (6) obtain additional product-related data. However, the vision of digital twins applied to supply chains is only now starting to appear, with noteworthy examples in specific sectors like pharmaceuticals (Marmolejo-Saucedo 2020). Moreover, the existing guidelines are made for individual products (Tao et al. 2019) or specific organizations (Marmolejo-Saucedo 2020), lacking support for more complex settings (e.g., smart regions) where multiple digital twins can coexist (e.g., factory, warehouse facility, vehicle, among others), paving the way to new business ecosystems digital twins or smart region digital twins.

More recently, the term "digital twin" was introduced in agriculture and food supply chains (Pylianidis et al. 2021; Verdouw et al. 2021). The examples are vast and include digital twins for fields, trees, animal farms, greenhouses, and vehicles used in agriculture (Pylianidis et al. 2021). These systems are still in their first steps but can gradually increase functionalities (Pylianidis et al. 2021). There are also distinctive characteristics that digital twin designers must consider, namely, the perishable (or living) nature of "digital mirrored items", and the scale (e.g., a large farm) (Pylianidis et al. 2021), requiring an interdisciplinary approach to advance the field further.

On the one hand, there is a global need for redesigned, more sustainable, and circular food systems to achieve the purposes set by the UN Agenda 2030 (United Nations 2015). More specifically, the Sustainable Development Goals (SDGs) 2 (eradicate hunger, achieve food security and improved nutrition and promote agriculture), 11 (make cities and human settlements inclusive, safe, resilient and sustainable), and 12 (ensure sustainable consumption and production patterns). These goals are also mirrored in the GEOfood manifesto (Magma Geopark 2020) and confirmed by the contacts made with Geopark experts. On the other hand, the literature review allowed us to identify relevant contributions to sustainable food supply chains, organics recycling, and technological opportunities for new systems development.

Research Design

Case Presentation and Research Objective

Our research takes place in Estrela UNESCO Global Geopark (Estrela Geopark), a region in the Iberian central region with geological heritage. Food producers located in Geoparks need to implement best practices in green tourism, environmental production, and sustainable use of endogenous resources. In 2021, Geoparks launched the GEOfood brand in 26 areas around the globe, recognizing local food producers that comply with GEOfood standards (Magma Geopark 2020): sustainability (use local raw materials and reduced transportation), cooperation, and tradition presentation. Estrela Geopark is one of the GEOfood network members and is interested in exploring the potential of digital twins for the food supply chain in their 2,216 km^2 territory, which covers nine municipalities of the Serra da Estrela region (central inner region of Portugal).

Our research involves a symbiotic relationship with Estrela Geopark. On the one hand, local experts provide valuable information about the regional context and jointly validate the artifact and design principles with the research team. The Estrela association has a multidisciplinary scientific board (e.g., sustainability, earth sciences) with the potential to address the different needs of a regional digital twin. On the other hand, the artifacts offer a new solution to more easily supervise compliance with GEOfood's guidelines and identify priorities for regional development policies.

According to their experts, composting organic material (e.g., fruits, weeds, dry leaves, food scrap, or sawdust) is one of the most ground-breaking phases of the supply chain to adopt digital twins. First, because it is one of the less disseminated in the community. Second, the (re)introduction of local (endogenous) food waste in the supply chain contributes to reducing (1) chemical fertilizers and (2) regional footprint. Third, strengthen the fragile links between urban areas (major food waste generators) and rural areas (major compost users) of the Geopark. Finally, it would decisively contribute to the overall aim of Geopark policy and GEOfood adoption by the local food producers. Recent digital twin reviews suggest that "[s]*ignificant research efforts need to be made on the application of a digital twin for improving the sustainability performances in each application context*" (Semeraro et al. 2021). Therefore, the main research objective of this study is formulated as follows: *design a smart region digital twin, according to GEOfood standards*.

Design Science Research at Estrela Geopark

Design science research (DSR) is an iterative research approach to design innovative artifacts applied in natural settings (vom Brocke and Maedche 2019; March and Smith 1995). The "design cycle is the heart of the design science research project" (Hevner et al. 2004) and essentially consists of three main activities: (1) building an artifact; (2) evaluating it; and (3) subsequent feedback to refine the design (Hevner et al. 2004). This set of activities works best when using an iterative process (i.e., a DSR project composed of several design cycles), as it is possible to take better advantage of the lessons learned through the research and reduce the project complexity and unpredictability (Hevner et al. 2004). DSR includes six essential dimensions (vom Brocke and Maedche 2019): problem description (P), input knowledge (IK), research process (RP), key concepts (KC), solution description (SD), and output knowledge (OK).

According to the contacts made with the Estrela Geopark, composting is essential for deploying sustainable practices in Geoparks. New digital solutions are necessary to improve local food supply chains, and digital twins have not yet been used at a regional level (P). Therefore, in parallel with the experts' insights, the authors have done a comprehensive literature review in the fields of the food supply chain, community composting, smart composting, and digital twins (IK, summarized in Section 3). The research process started with the identification of critical parameters for smart composting, specification of the digital twin using goal modeling techniques (ITU-T 2012), development of a real-scale model, and projectability (Baskerville and Pries-Heje 2019) to the region of Estrela Geopark (RP). According to Hevner et al. (2004), DSR includes three essential cycles: (1) relevance cycle, (2) rigor cycle, and (3) design cycle. The first two provide inputs to the design cycle. On the one hand, our relevance cycle is ensured by Estrela Geopark experts, GEOfood producers, and the community, establishing the design requirements and performing a joint evaluation. On the other hand, the literature review, the GEOfood manifesto (Magma Geopark 2020), and the DSR guidelines create our knowledge base for the rigor cycle (Hevner et al. 2004).

The nature of Geoparks and the food products produced by the local companies are relevant to this study. These regions share geological, social, and economic characteristics (e.g., agriculture and food production), and in many situations like Estrela Geopark, people are moving to more urban areas. Therefore, the concept of digital tween fleet (a group of similar physical objects producing valuable data) and the requirements of the GEOfood brand (promote best practice in local food companies and the cohesion of the urban-rural territory) are important concepts to include in our DSR (KC). The digital twin system must include a physical layer installed in a real-scale smart composter and a digital layer – interface using a 3D model, monitoring, and messaging system.

Finally, the output knowledge (OK) includes (1) the digital twin instantiation and (2) the formulation of design principles to deploy regional digital twins. These two outcomes are possible to achieve in DSR projects aiming to ensure application relevance in specific contexts and the rigor required for knowledge extraction (Hevner et al. 2004).

Roadmap for Iterative Development of Smart Region Digital Twins

Our research proposes an approach to developing digital twins for local food supply chains of endogenous (regional) products. Therefore, we planned the iteration of five DSR design cycle, where each DSR design cycle will focus on one of the local food supply chain steps.

The first DSR design cycle, already underway, focused on closing the loop of the food supply chain through community composting. Although this step can be seen as the "final frontier" of the food supply chain, it was a priority for the Estrela Geopark specialists. According to them, it was an opportunity to design an effective "recycling" tool for food waste and, simultaneously, foster urban-rural links. Some producers already make their compost and use it to fertilize their agricultural fields, but the amount of compost generated is insufficient. Thus, extending composting to the entire region involving the community in urban centers will make it possible to generate enough compost for GEOfood producers. In turn, the digitalization of this process will enable the Geopark managers responsible for ensuring compliance with the GEOfood guidelines to control whether certified producers are raising compost and thus ensure the use of fertilizers of natural origin rather than chemical ones. These factors highlight the interest in implementing this new practice in the region and its digitalization. However, the manual checking and maintenance of the compost heap will also be performed by specialized municipal workers to ensure the quality of the compost produced.

The second DSR design cycle will focus on the production step. As a practical case, we have chosen the Serra da Estrela cheese production. It is the most representative endogenous product of the region and has a significant economic impact. We will approach the production of Serra da Estrela cheese under a holistic view, i.e., focusing on the cheese manufacturing process, milk production, sheep, and pasture management. Monitoring these resources is vital to the production of Serra da Estrela cheese as they guarantee the quality and reliability of this product, which is often counterfeit due to its high value. Furthermore, this DSR design cycle will allow us to improve the digital twin that will enable Estrela Geopark to monitor the compliance of certified producers with the GEOfood guidelines.

The third DSR design cycle will focus on the distribution phase of the local food supply chain. On the one hand, many local food producers accumulate the functions of transporters and sellers, marketing their products in local markets. On the other hand, some producers sell their products to small local retain chains, which are resold in small shops. Hence, the digital twin should be flexible to integrate different distribution alternatives to guarantee traceability and food safety of their products and, simultaneously, provide indicators to Estrela Geopark to improve the daily use of food km zero.

The fourth DSR design cycle will focus on consumption. This cycle aims to involve consumers in the supply chain, where they will be able to provide feedback about the product consumed and check historical records since the production phase, enabling a broad form of food traceability. The digital twin may be used to collect food consumption data like possible contaminations, helping to avoid their propagation, for example, in a specific lot.

Finally, the fifth and last DSR design cycle will try to connect the links that were not united in the previous iterations and create an end-to-end regional digital twin. The final iteration should allow Estrela Geopark to extract knowledge for regional policies aiming at sustainable development and strengthening the GEOfood brand.

Results

This section details the physical and digital layers of the community composting digital twin developed during the first DSR design cycle.

The Physical Twin Layer for GEOfood Composting

The prioritization of locations for each composting unit placement targets (1) regional cohesion (waste pick up in the urban zone for incorporation in the nearest rural area), (2) optimized control (municipalities are main shareholders of Estrela Geoparks, allowing daily contact with each structure via their staff), and (3) endogenous resources (the composting bin structure can be built using local wood).

Figure 1 shows the composting bin structure.

Figure 1. Deployment of the physical twin layer

Figure 1 portrays a real structure incorporating sensors and communication devices. Among the multiple possibilities for designing composting units, the team decided to use local (natural) materials at this stage (top cover structure removed to show the interior details).

In this case, the type of organics waste includes leaf, non-animal food scraps like fruit, vegetables, dust, or wood (although other materials can be used) that are easier to obtain from municipality staff and inhabitants.

Unfolding the Digital Twin Layer

Pairing the physical and digital layers requires particular attention. For example, the "digital mirror" of the composting unit must be prepared to integrate data from the fleet – other composting units in the region, not restricted to a single device.

Four main building blocks are interconnected, namely: (1) the IoT infrastructure detailed in the previous section; (2) a Low Power Wide Area Network (LPWAN) using LoRa; (3) the application server that includes a NoSQL Mongo database and the software-related specifications developed in Python; and (4) two end-user devices selected for interaction with the regional digital twin. Each IoT-enabled composting bin sends the collected data to the application server. However, it will require a LoRaWAN gateway that will serve as an interface to receive the LoRa signal emitted by the IoT-enabled devices and send the received data through a POST request to the REST server. The mobile application is detailed in Monteiro et al. (2021), assisting the end-users in depositing their food waste and GEOfood producers in picking up the compost. The system managers (i.e., those responsible for the Estrela Geopark) will be able to visualize in real-time the status of the whole composting network through a web browser.

The local producer interface is straightforward, showing the nearest composter ready to pick up (GEOfood promotes zero-kilometer food products) and the web forms to validate compost pick up using smartphone location and user ID. Confirming which producer empties the community composter is essential to identify quantities recycled by the local food supply chain (e.g., by type of producer, municipality) and footprint reduction.

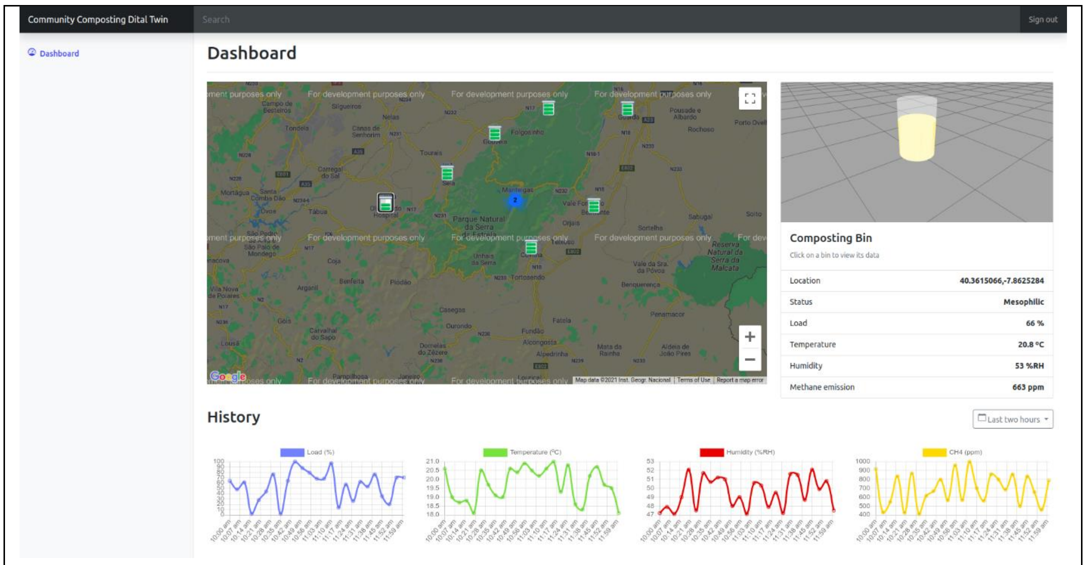

Figure 2. Digital twin dashboard GUI

Figure 2 integrates the digital twin fleet of composting units (map display and navigation available on the top-left of the dashboard), the 3D representation of the selected fleet unit on the right, the real-time snapshot of the system condition, and past historical data (below) of each unit or the fleet. Only the leftmost composting unit presented in the figure (white border) is acquiring real-time data. The other composting units are planned locations in more urbanized areas of Estrela Geopark.

The design and development of the digital twin revealed the challenges of a regional scale. Different layers must be considered to support an integrated replica of sociotechnical practices. The physical and digital links are interconnected and do not work correctly in isolation. On the one hand, the physical link enables sensing, composting and controlled access to the smart composter. On the other hand, the digital part enables social interaction and "make sense of data".

Discussion

The smart region digital twin enables different stakeholders in (1) the identification of the nearest processing unit via a mobile app, (2) real-time evaluation of the product supply chain, producing regional indicators valuable to Estrela Geopark, and (3) advancing the circular economy. Six preliminary design principles (DP) are derived to express prescriptive DSR theory (vom Brocke and Maedche 2019) and guide the development of future regional digital twins aggregating a fleet of similar twins.

DP1: Start with a top-down approach to create the regional digital twin architecture. Although the smart composting bin design could start immediately, there are risks of missing information necessary for the higher levels' digital twins (e.g., the best geographic location of the lowest layer digital twin). Our approach started with identifying the requirements for Estrela Geopark and the newly created GEOfood brand. The digital twin must be aligned with the regional strategy.

DP2: Gradually identifying regions of interest in the smart region. Our region includes different urban and rural areas with specific needs (e.g., municipality digital twin to support maintenance). Although it is possible to include smart composters in rural areas, most of the inhabitants in that zone are already reusing their waste in the fields, reducing their interest in community devices.

DP3: Delineate the supply chain digital twin. Flows of human and non-human entities are identified at this stage. Our project focuses on the final frontier of food supply chains and finds differences in the flow of materials (e.g., collected in urban areas to use in rural areas). Circular economy requirements and the technical aspects of the organic recycling supply chain are also addressed at this stage.

DP4: Select the smallest fleet of interest. The Estrela Geopark digital twin will only work if a fleet of composting units is in place, sharing data with the central database and the nearest stakeholders. For example, traveling from one end of the Geopark region to another is not feasible to pick up compost (disregards "zero-kilometer" goals). Therefore, the fleet is used to create a composting network.

DP5: Specify the details for the physical and digital elements. The smallest units of the digital twins are designed at this stage (e.g., IoT layer, digital interface, and communications).

DP6: Instantiate the system with a bottom-up approach. Testing and validation can evolve gradually, deploying the smallest "mirrors" in specific locations, learning with the process, and continuously tuning the smart region digital twin. Pilot projects are desirable at this stage.

The six design principles are aimed at various stakeholders, from developers (DP1, DP2, and DP4), decision-makers (DP1, DP2, and DP4), IT experts (DP4 and DP5), to end-users (DP6). DP1-DP4 cover the early stages of project conception and design and focuses on regional aspects. DP5 concentrates on technology selection and DP6 on sustainability indicators. Nevertheless, these initial DP require a better formulation in the next research steps, adopting Gregor et al. (2020) guidelines.

Conclusion

This short paper presented a DSR project aiming to create a region-wide digital twin for organics composting, with potential scalability for the network of Geoparks. A fleet of physical composting units is coupled with a "micro" digital twin structure (individual composting units) and "macro" (regional) digital twin integrating data for seven municipalities in a relevant geological area promoting (1) circular food supply chains, and (2) endogenous food sustainability. The prototype is instantiated in the Estrela Geopark region and is expected to boost their local GEOfood network.

For theory, this research provides six preliminary design principles, which may assist researchers and practitioners in deploying future smart region digital twins. For practice, the developed solution will provide the foundations of a digital twin instantiation, enabling Estrela Geopark managers to verify compliance with GEOfood guidelines by certified producers and assist in decision-making to build policies that foster sustainable development in the region.

The challenges the GEOfood brand poses are common to all 26 Geoparks. Therefore, the proposed solution can be transferred to the other Geoparks that belong to the worldwide GEOfood brand, adapting to the peculiarities of each region. On a local scale, more intelligent food supply chains can contribute to more balanced consumption (minimizing resources used for food production) and circular practices. Our research can contribute to mitigating, at a regional level, the demand for food and more efficient use of resources, making these regions more autonomous and resilient, which is a necessity of our era. Nevertheless, a higher layer (i.e., inter-Geoparks) could enable the flow of data and food between Geoparks, leading to the creation of digital twins that span countries and continents. Sharing data between digital twins (the fleet) can assist decision-making and best practice diffusion. In addition to the technologies already employed, blockchain and artificial intelligence will be crucial. The former ensures the traceability and security of both data and food, and the latter correlates the data with helpful predictions (e.g., raw materials, energy, water, compost) and recommendations for the different regional stakeholders.

There are also limitations that must be stated. First, this phase of our DSR achieved a real-scale instantiation of the digital twin. It focused on a detailed physical layer architecture, but the system is not yet deployed in the different municipalities of Estrela Geopark. Moreover, waste recycling and pick-up are still very controlled (not yet diffused to the public), lacking a regional scale test. Future work is necessary to understand the impact in the daily routines of staff supervising and managing each structure in a decentralized way. Nevertheless, there is already evidence of the positive cost-benefit analysis of composting in other regional settings. Second, this DSR cycle is not yet exploring the incentives for GEOfood producers. For example, gaining GEOfood points according to the quantity of food waste recovered and creating sustainability rankings in the region. Third, the regional digital twin aggregating the fleet will include instant messaging at the application layer to notify local managers of each municipality for composting unit maintenance. This interaction is not yet implemented and will evaluate the system's social impact (e.g., user acceptance and operational issues). Moreover, the system can be extended with producer-specific composting digital twins focusing on rural areas – creating a new fleet layer to the digital twin architecture.

The layered vision of digital twins for food supply chains and smart regions is a fascinating topic for future research. This DSR only scratches the surface of digital twin ecosystems. More research is necessary to guide the deployment of multi-layered digital twins that need horizontal (fleet), vertical (regional and product-specific), and end-to-end cyber-physical integration in a circular supply chain.

Acknowledgments

This work is funded by national funds through the FCT – Foundation for Science and Technology, I.P., within the scope of the project CISUC-UID/CEC/00326/2020 and by the European Social Fund, through the Regional Operation Program Centro 2020. The first author is funded by FCT under the Ph.D. grant 2022.09950.BD.

References

Baskerville, R., and Pries-Heje, J. 2019. "Projectability in Design Science Research," *Journal of Information Technology Theory and Application* (20:1), p. 3.

Bradford, A., Sundby, J., Truelove, A., and Andre, A. 2019. "Composting in America - A Path to Eliminate Waste, Revitalize Soil and Tackle Global Warming." (https://policycommons.net/artifacts/1570276/composting-in-america/2260055/).

vom Brocke, J., and Maedche, A. 2019. "The DSR Grid: Six Core Dimensions for Effectively Planning and Communicating Design Science Research Projects," *Electronic Markets* (29:3), pp. 379–385. (https://doi.org/10.1007/s12525-019-00358-7).

Dantas, T. E. T., de-Souza, E. D., Destro, I. R., Hammes, G., Rodriguez, C. M. T., and Soares, S. R. 2021. "How the Combination of Circular Economy and Industry 4.0 Can Contribute towards Achieving the Sustainable Development Goals," *Sustainable Production and Consumption* (26), pp. 213–227. (https://doi.org/10.1016/j.spc.2020.10.005).

GE. 2016. "Minds + Machines: Meet A Digital Twin." (https://youtu.be/2dCz3oL2rTw).

Glaessgen, E., and Stargel, D. 2012. "The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles," in *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, 20th AIAA/ASME/AHS Adaptive Structures Conference, 14th AIAA*, Reston, Virigina: American Institute of Aeronautics and Astronautics, April 23, pp. 1–14. (https://doi.org/10.2514/6.2012-1818).

Gregor, S., Kruse, L., and Seidel, S. 2020. "Research Perspectives: The Anatomy of a Design Principle," *Journal of the Association for Information Systems* (21), pp. 1622–1652. (https://doi.org/10.17705/1jais.00649).

Hevner, March, Park, and Ram. 2004. "Design Science in Information Systems Research," *MIS Quarterly* (28:1), p. 75. (https://doi.org/10.2307/25148625).

ITU-T. 2012. *User Requirements Notation (URN) – Language Definition (Z.151, 10/2012)*, International Telecommunication Union.

Lezoche, M., Hernandez, J. E., Alemany Díaz, M. del M. E., Panetto, H., and Kacprzyk, J. 2020. "Agri-Food 4.0: A Survey of the Supply Chains and Technologies for the Future Agriculture," *Computers in Industry* (117), p. 103187. (https://doi.org/10.1016/j.compind.2020.103187).

Liu, Y., Ma, X., Shu, L., Hancke, G. P., and Abu-Mahfouz, A. M. 2021. "From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges," *IEEE Transactions on Industrial Informatics* (17:6), pp. 4322–4334. (https://doi.org/10.1109/TII.2020.3003910).

Magma Geopark. 2020. *The GEOfood Manifesto*. (https://magmageopark.no/wp-content/uploads/2021/04/GEOFOOD-MANIFESTOEngl.pdf).

March, S. T., and Smith, G. F. 1995. "Design and Natural Science Research on Information Technology," *Decision Support Systems* (15:4), pp. 251–266. (https://doi.org/10.1016/0167-9236(94)00041-2).

Marmolejo-Saucedo, J. A. 2020. "Design and Development of Digital Twins: A Case Study in Supply Chains," *Mobile Networks and Applications* (25:6), Mobile Networks and Applications, pp. 2141–2160. (https://doi.org/10.1007/s11036-020-01557-9).

Monteiro, J., Barata, J., Gomes, H., and Castro, E. 2021. "Deploying Smart Community Composting in Estrela UNESCO Global Geopark: A Mobile App Approach," in *Information Systems Development: Crossing Boundaries between Development and Operations (DevOps) in Information Systems (ISD2021 Proceedings)*, E. Insfran, F. González, S. Abrahão, M. Fernández, C. Barry, M. Lang, H. Linger, and C. Schneider (eds.), Valencia, Spain: Universitat Politècnica de València, August 9. (https://aisel.aisnet.org/isd2014/proceedings2021/sustainable/2).

Pylianidis, C., Osinga, S., and Athanasiadis, I. N. 2021. "Introducing Digital Twins to Agriculture," *Computers and Electronics in Agriculture* (184:July 2020), p. 105942. (https://doi.org/10.1016/j.compag.2020.105942).

Semeraro, C., Lezoche, M., Panetto, H., and Dassisti, M. 2021. "Digital Twin Paradigm: A Systematic Literature Review," *Computers in Industry* (130), p. 103469. (https://doi.org/10.1016/j.compind.2021.103469).

Smetana, S., Aganovic, K., and Heinz, V. 2021. "Food Supply Chains as Cyber-Physical Systems: A Path for More Sustainable Personalized Nutrition," *Food Engineering Reviews* (13:1), pp. 92–103. (https://doi.org/10.1007/s12393-020-09243-y).

Tao, F., Sui, F., Liu, A., Qi, Q., Zhang, M., Song, B., Guo, Z., Lu, S. C.-Y., and Nee, A. Y. C. 2019. "Digital Twin-Driven Product Design Framework," *International Journal of Production Research* (57:12), pp. 3935–3953. (https://doi.org/10.1080/00207543.2018.1443229).

United Nations. 2015. "Transforming Our World: The 2030 Agenda for Sustainable Development." (https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf).

Verdouw, C., Tekinerdogan, B., Beulens, A., and Wolfert, S. 2021. "Digital Twins in Smart Farming," *Agricultural Systems* (189:May 2020), p. 103046. (https://doi.org/10.1016/j.agsy.2020.103046).

Vieira, G., de Castro, E., Gomes, H., Loureiro, F., Fernandes, M., Patrocínio, F., Firmino, G., and Forte, J. 2020. "The Estrela Geopark—From Planation Surfaces to Glacial Erosion," in *World Geomorphological Landscapes*, pp. 341–357. (https://doi.org/10.1007/978-3-319-03641-0_27).