A Competency Framework for Digital and Precision Agriculture Professionals: Structure and Core Domains

Lucia Cuque[1]; João Mattar[2]

[1] *Pontifícia Universidade Católica de São Paulo, Brazil.*
[2] *Pontifícia Universidade Católica de São Paulo, Brazil.*

A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

Abstract.

*The rapid expansion of digital and precision agriculture technologies has significantly increased the complexity of contemporary agricultural production systems. The integration of technologies—including GNSS-guided machinery, geospatial analytics, sensor networks, artificial intelligence, robotics, and advanced analytics—requires professionals capable not only of operating digital tools, but also of understanding agronomic processes, systems integration, and data-driven decision-making. Despite this growing complexity, no comprehensive competency framework currently integrates technological, agronomic, and systemic requirements into a coherent model for digital and precision agriculture professionals. This study proposes a competency framework derived from a literature review, occupational taxonomy mapping, and field research. Peer-reviewed publications addressing competencies in the context of digital, precision, and smart agriculture were identified through a structured search of Scopus, Web of Science, and Google Scholar, using predetermined inclusion and exclusion criteria. A total of 61 articles were selected for in-depth analysis. In parallel, 98 occupations related to digital and precision agriculture were identified and analyzed across three major classification systems: European Skills, Competences, Qualifications, and Occupations (ESCO), Occupational Information Network (O*NET), and the Brazilian Qualifications Framework (QBQ). Comparative mapping procedures were applied to identify recurring competency domains, structural patterns, and cross-domain interdependencies. Through focus groups and interviews, 28 participants from 16 distinct digital agriculture stakeholders took part in the field research. Some criteria for data evaluation and competency selection—like citation frequency and participant-driven terminology—were established. To ensure an organized structure, the resulting framework adopts a hierarchical competency structure. The framework is organized into two overarching categories: Knowledge and Skills, and Attitudes. Within these categories, twelve core domains were identified, encompassing Cognitive and Analytical Skills; Management and Decision-Making; Technological and Digital Skills; Engineering and Applied Technology; Natural Sciences; Agricultural Systems; Entrepreneurship; Engagement Skills; Specialized Machinery and Equipment Operation; Self-efficacy; Working with Others; and Ethics. The proposed model functions as a system-level competency framework aligned with the technological architecture of precision agriculture systems, including data acquisition, processing, analytics, and field-level implementation. The framework provides a structured basis*

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture. EXAMPLE: Last Name, A. B. & Coauthor, C. D. (2026). Title of paper. In Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture and Brazilian Congress on Precision and Digital Agriculture.

for curriculum development, professional certification, workforce planning, and strategic workforce development in increasingly digitalized agricultural ecosystems.

Keywords.
Agriculture 4.0; Digital agriculture; Agricultural professionals; Workforce development; Digital Skills.

Introduction

With the growth of the global population, agriculture is challenged to increase food production while simultaneously reducing environmental impacts and socioeconomic implications (Silveira, Lermen, & Amaral, 2021). As a measure to support these challenges, there is broad consensus that agricultural mechanization, including automation and Precision Agriculture (PA), can significantly transform agri-food systems (Winarno et al., 2025).

The development of agricultural management based on the principles of Precision Agriculture is part of what has been termed Agriculture 4.0 (Molin et al., 2020). Digital Agriculture (DA) has its conceptual foundations in Agriculture 4.0 (Enkhjav & Davaasambuu, 2019; Molin et al., 2020) and is characterized using cutting-edge technologies in food production (Bolfe et al., 2020). The essence of Digital Agriculture lies in generating value from data (Molin et al., 2020; Charatsari et al., 2022; FAO, 2022), increasing agricultural automation (Charatsari et al., 2022), and developing actionable intelligence and added value from these data (FAO, 2022).

The incorporation of emerging technologies into agriculture, such as robotics (Charatsari et al., 2022; Hasan, Aftah, & Syakban, 2022), drones (Adel, 2023; Massruhá et al., 2020), advanced sensors, image-processing algorithms, 3D reconstruction methods (Silveira, Landaverde & Barbedo, 2026), Artificial Intelligence (AI), the Internet of Things (IoT), machine learning (Bolfe et al., 2020), digital twins (Silveira, Landaverde & Barbedo, 2026), among others, constitutes a widely recognized approach to increasing agricultural production and ensuring sustainability.

On the other hand, barriers to the progress of Digital Agriculture and its development have been reported by farmers, academics, and specialists. These include difficulties in recruiting qualified and specialized labor (Rossi Junior & Doyle, 2023; Silveira, Lermen, & Amaral, 2021), the high cost of such labor, issues related to professionals' educational backgrounds (Silveira, Lermen, & Amaral, 2021), shortages of digital skills (Sun et al., 2022), the absence of competencies required for Digital Agriculture in agricultural, technical, and university curricula (Silveira et al., 2023), difficulties in accessing training in agricultural technologies, and the costs involved in hiring service providers (Rossi Junior & Doyle, 2023).

Farmers with higher levels of education tend to adopt technological solutions, such as internet-based tools (Sun et al., 2022). Revising university curricula and professional development programs is therefore necessary to ensure that current agribusiness professionals and future generations acquire the competencies needed to capitalize on technological opportunities in agriculture (Weersink et al., 2018; FAO, 2022).

Carbone et al. (2006) and Brandão (2023) associate the concept of competencies with the mobilization and combination of individual attributes, such as knowledge, skills, and attitudes, that are necessary to perform tasks and carry out professional activities within a specific context.

Workforce training initiatives require appropriate national strategies and the involvement of multiple stakeholders (European Commission, 2020). Occupational taxonomies, as well as competency frameworks, provide structures that ensure standardized terminology for the competencies required across different occupations (Altamirano & Amaral, 2020).

The research presented in this paper sought to answer three questions. The first was: What strategies were adopted to assess the state of the art, build the theoretical foundation, and support the development of a competency framework for professionals working in Digital Agriculture? The second question sought to understand: What competencies are required to perform functions in Digital Agriculture, according to field research participants representing different Digital Agriculture stakeholders? The third question asked: Which competency areas should be included in a competency framework designed for professionals working in Digital Agriculture?

This study explains the literature review methods employed in the research, including academic articles, documents from international organizations, and official records from the governments of Brazil, the United States, and Europe. A synthesis of the essential competencies mentioned by field research participants is presented, highlighting the frequency observed in semi-structured interviews and focus groups. Finally, the criteria established for creating the competency framework for Digital Agriculture professionals are presented, along with its four levels of detail and, ultimately, the competency categories and areas corresponding to the first and second levels of the framework.

Methods

Social research methodology and document analysis are strategies that support the identification of essential competencies by revealing public content and the meanings and underlying intentions associated with the object of study (Brandão, 2023). Qualitative field research seeks to understand phenomena and the interpretations that study participants attribute to them (Mattar & Ramos, 2021).

This study can be characterized as applied research with descriptive objectives and a cross-sectional design. Data sources included documentary, bibliographic, and field research, and the methodology adopted a mixed-methods exploratory sequential design.

The field research included the definition of the sample of Digital Agriculture stakeholders; the development and validation of the interview guide (Rubin & Rubin, 2011); data collection through semi-structured interviews (Manzini, 2003) and focus groups (Mattar & Ramos, 2021); and the analysis of the collected data in accordance with the data coding procedures proposed by Saldaña (2013).

Literature Review

The construction of the conceptual and theoretical framework was carried out through two complementary actions. The first involved a literature review of academic articles, following the guidelines proposed by Okoli (2019). The second strategy involved investigating selected occupations and their associated competencies in occupational taxonomies and competency frameworks. These processes were conducted at different stages of the research.

Scientific Articles

The first stage of the literature review consisted of a search of academic databases. The search scope included terms related to Digital Agriculture (DA), namely: agriculture, digital agriculture, Agriculture 4.0, technologies, competence, competences, competency, competencies, skill, skills, ICT, and ICTs. The search was conducted in three databases: Scopus, Web of Science, and Google Scholar. The search strategy was restricted to the title field and yielded 55 publications from Scopus, 17 from Web of Science, and 340 articles from Google Scholar. The literature review process followed the eight steps recommended by Okoli (2019). Exclusion criteria were then applied, resulting in the selection of 61 articles for data extraction.

The data extracted from each article aimed to identify the research objectives; the conceptualization of Digital Agriculture, Agriculture 4.0, and Precision Agriculture; the challenges and benefits of Digital Agriculture; barriers and opportunities related to the use of Information and Communication Technologies (ICTs) in agricultural activities; characteristics of the research participants and contexts; the main Digital Agriculture stakeholders; competencies recommended for professionals working in Digital Agriculture; information about available competency structures; data regarding youth participation in the agricultural sector; information about challenges faced by women in agriculture; details of training opportunities offered to Digital Agriculture professionals; and information related to sustainability and the environment.

With specific regard to competencies, 106 competencies—namely knowledge, skills, and attitudes—were identified in the articles analyzed during the literature review.

Occupational Taxonomies and Competency Frameworks

As a result of the attempt to triangulate bibliographic data with the data collected through the semi-structured interviews conducted in 2023, it was decided to further strengthen the theoretical framework. This additional work included investigating occupational taxonomies, competency models, and documents produced by governmental bodies and national and international organizations.

The taxonomies and frameworks investigated in this study were: the Global Skills Taxonomy (World Economic Forum, 2021); the Brazilian Qualifications Framework (Quadro Brasileiro de Qualificações – QBQ) (Brazil, 2024, 2025); the Occupational Information Network framework (O*NET) (United States, 2024, 2025); and the European Skills, Competences, Qualifications and Occupations (ESCO) framework (European Commission, 2024, 2025). The selection of occupational taxonomies and competency frameworks followed the following criteria: (i) being developed by a government agency or a nationally or internationally recognized institution; (ii) being periodically updated; (iii) describing occupations, as well as the knowledge, skills, and attitudes associated with professional practice; and (iv) presenting data related to Digital Agriculture (DA), Precision Agriculture (PA), or Smart Agriculture (SA).

The core skills identified in the *Future of Jobs Report 2025* (World Economic Forum, 2025) for the Agriculture, Forestry, and Fishing sector were also considered, as they offer insights into the perspectives of organizational leaders worldwide on the competencies required of professionals in this sector. The process of searching for information within occupational taxonomies and competency frameworks was conducted in three distinct stages, following different selection criteria.

Field Research

The field research was structured into four phases, including the development of the research instrument, the conduct of interviews, the coordination of focus group meetings, and the analysis of the collected data.

The research instrument consisted of a single set of questions suitable for both interviews and focus groups, following the guidelines of the responsive semi-structured interview method (Rubin & Rubin, 2011). The topics addressed included trends in the Brazilian agricultural sector; understandings of Digital Agriculture (DA), as well as its advantages and disadvantages for farmers; the main challenges associated with the implementation of Digital Agriculture in Brazil; the identification of the main Digital Agriculture stakeholders; perceptions of the effects of Digital Agriculture on the labor market; the identification of competencies, namely the knowledge, skills, and attitudes required for professionals working in Digital Agriculture; the identification of competencies that are still scarce among current Digital Agriculture professionals; and an open space for additional comments, among other questions.

The research project, supporting documents, and research instrument (the interview guide) received approval from the Research Ethics Committee of the Pontifical Catholic University of São Paulo (PUC-SP) under CAAE number 73017923.9.0000.5482 and approval number 6.578.497.

Results and Discussion

This section presents a partial list of the knowledge, skills, and attitudes identified in the field research, explains the criteria adopted to develop the competency framework for professionals working in Digital Agriculture (DA), details the framework's levels of granularity, and presents Levels 1 and 2 of the framework.

Searches and Data Collected from Occupational Taxonomies and Competency Frameworks

The first searches for occupations within the taxonomies and frameworks were conducted on February 24, 2024, in ONET; on February 29, 2024, in ESCO; and on July 21, 2024, in the Brazilian Qualifications Framework (QBQ). In the search systems of the ONET and ESCO platforms, as well as in the Excel file generated by the QBQ website, the terms “agricultura digital,” “digital agriculture,” “agricultura de precisão,” “precision agriculture,” “agricultura inteligente,” and “smart agriculture” were used to identify occupations associated with these expressions in each dataset.

In ONET, in addition to the terms mentioned above, occupations classified under the Farming, Fishing, and Forestry category were examined, as well as occupations included in Industry, specifically those related to Agriculture, Forestry, Fishing, and Hunting. Occupation descriptions were analyzed, and 14 occupations from QBQ, 18 from ONET, and 36 from ESCO were selected for the study due to their association with Digital Agriculture stakeholders.

Table 1 presents the occupations selected from ESCO (2024), O*NET (2024), and QBQ (2024) based on the terms used in the first search.

Table 1. Occupations selected in the first search conducted in ESCO, O*NET, and QBQ

Taxonomy and Framework	Occupations
ESCO	Agricultural engineer, agricultural equipment design engineer, agricultural inspector, agricultural machinery and equipment distribution manager, agricultural machinery technician, agricultural policy officer, agricultural raw materials, seeds and animal feeds distribution manager, agricultural scientist, agricultural technician, agriculture, forestry and fishery vocational teacher, agronomist, automation engineer, bioengineer, chief executive officer, chief operating officer, chief technology officer, environmental engineer, farm manager, import export manager in agricultural machinery and equipment, import export manager in agricultural raw materials, seeds and animal feeds, import export specialist in agricultural machinery and equipment, import export specialist in agricultural raw materials, seeds and animal feeds, irrigation system installer, land-based machinery operator, land-based machinery supervisor, livestock advisor, mechanical engineers, precision engineer, production engineer, rental service representative in agricultural machinery and equipment, research engineer, surveying technician, technical sales representative in agricultural machinery and equipment, test engineer, wholesale merchant in agricultural machinery and equipment, Wholesale merchant in agricultural raw materials, seeds and animal feeds.
O*NET	Agricultural engineers, agricultural equipment operators, agricultural inspectors, agricultural sciences teachers, postsecondary agricultural technicians, cartographers and photogrammetrists, conservation scientists, digital forensics analysts, farm and home management educators, farm equipment mechanics and service technicians, farmers, ranchers, and other agricultural managers, farmworkers and laborers, crop, nursery, and greenhouse, first-line supervisors of farming, fishing, and forestry workers, food science technicians, graders and sorters, agricultural products, precision agriculture technicians, soil and plant scientists, web and digital interface designers.
QBQ	Agricultural engineer, agricultural machinery assembler, combine harvester operator, multi-skilled agricultural producer, general agricultural producer, peanut producer, canola producer, sunflower producer, soybean producer, rice producer, small fruit producer, corn and sorghum producer, agricultural technician, agricultural tractor driver.

Note: elaborated by the authors, based on ESCO (2024), O*NET (2024) and QBQ (2024).

The second search across O*NET, ESCO, and QBQ was conducted on October 30, 2024. On this occasion, it was decided to include in the study the competencies associated with occupations involved in Agricultural Operations Centers. The selection of the occupational titles investigated was supported by technical guidance and recommendations from professionals working at the National Union of Bioenergy (UDOP) and the Shunji Nishimura Faculty of Technology of Pompeia (FATEC Pompeia).

The occupational titles selected for this search were “data analyst,” “data scientist,” “data engineer," "data architect," "artificial intelligence/machine learning engineer," "business intelligence analyst," "data analytics engineer," and "data analytics." The occupations were searched in both Portuguese and English. A total of 13 occupations were identified across the three taxonomies and were subsequently validated by the respective professionals before proceeding with data extraction and analysis.

Table 2 presents the occupations selected from ESCO (2024), O*NET (2024), and QBQ (2024) in the second search conducted within the taxonomies and frameworks.

Table 2. Occupations selected in the second search conducted in ESCO, O*NET, and QBQ

Taxonomy and Framework	Occupations
ESCO	Artificial intelligence engineer, business intelligence manager, data analyst, data scientists, database architects, database designer, database engineer.
O*NET	Business intelligence analyst, data administrators, data scientist, database architects.
QBQ	IT solutions architect, data scientist.

Note: elaborated by the authors, based on ESCO (2024), O*NET (2024) and QBQ (2024).

Based on the analysis of information obtained from five interviews conducted with Digital Agriculture (DA) stakeholders between February and March 2025, it was found that certain technological skills and knowledge mentioned by these respondents had not been identified in the interviews and focus groups conducted in 2023 and 2024, nor were they present in the literature previously reviewed. Therefore, on May 23, 2025, a third search for occupations was conducted in the QBQ, ESCO, and ONET occupational taxonomies and competency frameworks, specifically targeting occupations associated with the technologies mentioned, namely: georeferencing, geostatistics, geotechnology, Geographic Information Systems (GIS), satellite connection systems, and interoperability. Table 3 presents the 17 occupations selected in this third search conducted in ESCO (2025), ONET (2025), and QBQ (2025).

Table 3. Occupations selected in the third search conducted in ESCO, O*NET, and QBQ

Taxonomy and Framework	Occupations
ESCO	Geographic information Systems specialist, cartographer, remote sensing technician, database integrator.
O*NET	Cartographers and photogrammetrists, computer systems engineers/architects, Geographic Information Systems technologists and technicians, precision agriculture technician, statisticians e telecommunications engineering specialists.
QBQ	Agricultural engineer, agronomist, cartographic engineer, information technology operations manager, forestry production and operations manager and researcher in earth and environmental sciences.

Note: elaborated by the authors, based on ESCO (2025), O*NET (2025) and QBQ (2025).

In ESCO (European Commission, 2024, 2025), a maximum of 4 levels of detail were established for the listed skills and knowledge. Therefore, even when a skill or a piece of knowledge contained more than four levels of granularity, only the first four levels were added to the research database. The information collected was organized into four categories: Level One, representing the broadest level; Levels Two and Three, corresponding to intermediate levels; and Level Four, representing the most specific level.

The QBQ (Brazil, 2024, 2025) presented competencies at different levels of granularity, and the number of levels varied according to the competency category. Four levels of detail were identified for skills, three levels for knowledge, and only two levels of granularity for attitudes. In O*NET, a single level of granularity was considered for knowledge and skills for each selected occupation.

Table 4. Consolidation of data collected from ESCO, O*NET, and QBQ

Taxonomy and Frameworks	DA, PA and SA (first search)				AOC Occupations (second search)				Complementary technologies (third search)			
	Occupations	K	**S**	**A**	**Occupations**	K	**S**	**A**	**Occupations**	K	**S**	**A**
ESCO	36	238	567	0	7	93	191	0	4	35	137	0
O*NET	18	23	109	0	4	33	101	0	6	16	95	0
QBQ	14	574	57	14	2	205	56	10	7	611	69	15
Total	68	835	733	14	13	331	348	10	17	662	301	15

Note: AOC = Agricultural Operations Centers; K = Knowledge; S = Skills; A = Attitudes. Elaborated by the authors, based on ESCO (2024, 2025), ONET (2024, 2025), and QBQ (2024, 2025).

The collected data were organized into tables in order to determine the frequency with which each piece of knowledge, skill, or attitude was identified across the selected occupations. The frequency of each competency was calculated as the number of times the same competency—that is, a piece of knowledge, a skill, or an attitude—was identified, divided by the total number of occupations analyzed. The data collected from all searches conducted in QBQ (Brazil, 2024, 2025), O*NET (United States, 2024, 2025), and ESCO (European Commission, 2024, 2025) followed the same procedure.

Competencies Collected in the Field Research

Twenty interviews were conducted, fifteen between 2023 and 2024 and five in 2025. The two focus group sessions took place in 2024 and involved 8 professionals. Both the interviews and the focus groups were conducted via a digital platform; audio recordings were made with participants' consent and analyzed without using any data analysis tools or software.

The selection of field research participants aimed to include representatives from diverse Digital Agriculture (DA) stakeholders. Table 5. Digital Agriculture stakeholders and field research participants summarizes, by data collection category, which Digital Agriculture stakeholders contributed to the study and the number of individuals in each category. The field research involved interactions with 28 participants representing 16 different Digital Agriculture stakeholders.

Table 5. Digital Agriculture stakeholders and field research participants

Data collection methods	Stakeholders	Number of participants
Interview	Agricultural machinery manufacturer	4
Interview	Public research company for agribusiness	3
Interview	Academy	3
Interview	Academy, technology, and biotechnology company for agriculture	1
Interview	Bioenergy Association	1
Interview	Agricultural Machinery Association	1
Interview	Biorefinery—sugar energy sector	1
Interview	Agricultural machinery dealership	1
Interview	Agricultural cooperative	1
Interview	Technology and digital solutions company for agribusiness	1
Interview	Manufacturer of grain storage, processing, and handling equipment	1
Interview	Agricultural producer and sugar energy industry	1
Interview	Private and non-profit research institution in the agricultural sector	1
Focus group	Academy	3
Focus group	Rural extension	3
Focus group	Family farming producers	2

Note: elaborated by the authors according to the profile of field research participants.

Although the set of questions included two specific competency-related questions, it was decided to analyze references to competencies in responses to all questions posed to field research participants. This allowed us to observe that some participants mentioned knowledge, skills, and attitudes essential to Digital Agriculture (DA) when answering other questions, without necessarily reiterating them in response to questions specifically addressing competencies. Another advantage of this strategy was that it provided a clearer perspective on the competencies considered most relevant by the professionals who participated in the field research.

For the analysis of data obtained from the focus groups, competency mentions were adopted as the fundamental unit of analysis. A criterion of single occurrence per session was established so that each competency was recorded only once per group, regardless of how many times the term was repeated during discussions of the same question.

The comprehensive analysis of all questions enabled the mapping of 583 competencies in total. Of these, 254 distinct competencies were identified by their literal nomenclature, while their consolidation through semantic similarity analysis remained pending at this stage of the process.

Table 6 presents the various knowledge, skills, and attitudes mentioned by field research participants in response to the questions posed, along with the frequency with which these competencies were cited.

Table 6. Distinct competencies identified across all field research questions

Citation frequency	Knowledge, Skills and Attitudes
20	Data analysis, and interpretation.
13	Agronomy, management, and artificial intelligence.
11	Multidisciplinary knowledge, and programming.
10	ICT (Information and Communication Technologies).
9	Communication.
8	Information technology, leadership, and GIS (Geographic Information System).
7	Computer science, understanding the production system, data, drones, and decision making.
6	Georeferencing tools; satellite imagery; telemetry.
5	Data application, big data, biology, understanding the likelihood of pests or diseases, data interpretation, Power BI, robotics, remote sensing application, satellites, and teamwork.
4	Algorithms, databases, digital skills, knowledge of agricultural equipment, curiosity, digital, soil physics, forming and/or working with multidisciplinary knowledge teams, geography, people management, languages, machine learning, agricultural machinery, Python, sensors, and technology.
3	Precision agriculture, digital literacy, automation, data science, Environmental, Social, and Governance (ESG) principles, data value extraction, geotechnology, emotional intelligence, logistics, yield mapping, mathematics, critical thinking, drone piloting, digital platforms, proactivity, data processing, software development, and animal husbandry.,
2	Agility, agricultural, farming, digital agriculture, analytics, self-learning, increasing productivity, banking, cartography, climate, commitment, communication via digital tools, connectivity, talent mapping, technical knowledge, financial knowledge, agricultural controllers, cooperation, deep learning, packaging, empathy, entrepreneurship, weather station, statistics, Microsoft Excel, digital tools, geostatistics, geoprocessing, agricultural waste treatment and disposal, cost management, time management, aptitude for testing, innovation, inputs, crop-livestock-forestry integration, interaction with other areas, map interpretation, IoT (Internet of Things), legislation, lifelong learning, marketing, mechanization, negotiation, new technologies, sensor operation, analytical thinking, persuasion, soil conservation, image processing; agribusiness processes; spraying; logical reasoning; rational use of water; traceability; networks; relationships, SAP, seasonality, seeds, sense of urgency, integrated crop-livestock-forestry systems, sustainability, using precision bio-inputs, veterinary medicine, and business acumen.
1	Openness to learning; troubleshooting; regenerative agriculture; precision agrometeorology; functional literacy; environmental; critical analysis; applications; acquiring new skills; continuous learning; IT architecture; artisanal food legislation and marketing; service delivery orientation; evaluating global robotics solutions; assessing cost-benefit ratios; biodigester; bio-inputs; developing sustainable production systems; sales channels for agricultural products; analytical capacity; adaptability; management capacity; synthesis skills; cell phones; cyberattack; cybersecurity; soil scientist; collaboration on social networks; collaboration within rural producer associations; digital marketing; compliance; behavior; analyzing agricultural operations; analyzing agricultural system differences (field vs. greenhouse) to evaluate global technology applicability; leveraging digital media; analyzing farmer needs and characteristics; evaluating new technologies and digital tools; assessing digital solution frameworks for agriculture; understanding the business and knowledge by product (crop); CRM (Customer Relationship Manager); dashboard; dedication; pesticides; developing solutions that generate value for the business; hardware development (equipment; robots); software development; water desalination; e-commerce; economics; gene editing; electronics; communication systems engineering; computer science and programming; electrical engineering; forestry engineering; basic education; intrapreneurship; utilizing extrapolations; interpolations; and heat maps; managing billing on an annual basis; image analysis; digital agriculture tools; georeferenced data analysis tools; business intelligence tools; filtering large volumes of information; flexibility; genetics; generating maps; remote management; quality management; willingness to learn; governance; GPS (Global Positioning System); behavioral skills; hardware; high board with irrigation; drone imagery; implements; nonconformity management; Vegetation Indices; infrastructure; analytical intelligence; data intelligence; internet; interoperability; reading reports; analyzing tractor-generated data; dealing with digital interfaces; dealing with people; computational language; harvest map; profit map; environment; genetic improvement; meteorology; digital media; multilingualism; business; data organization; rainy season; autopilot; continuous learning; making correlations between different subjects; maintenance reports; map reports; tractor performance in the field; crop rotation; managing failures; operating field vehicles; forming and managing cross-functional teams; utilizing digital platforms; crop sequence; digital solutions and tools; oil temperature; demonstrating organizational vision; TOTVS; data transmission and transfer; transportation and storage; cross-functionality; data processing; operating electronic diagnostic equipment (scanner); utilizing digital applications; wind farm; utilizing mobile and desktop applications; viewing maps; returning to study; and willingness to learn.

Note: elaborated by the authors.

The field research highlights the importance of multidisciplinary knowledge and skills among professionals and teams working in Digital Agriculture (DA) in two ways. The first is the explicit mention of the expression *'multidisciplinarity of knowledge,' with 11 citations, which may be associated with either the Cognitive Skills* or the Technological Skills competency area. The second is directly related to the analysis of specific competencies, which identified 12 distinct competency areas.

The competencies most frequently mentioned by field research participants belong to different competency areas, such as Agriculture, which is related, for example, to specific competencies such as agronomy and knowledge of agricultural production systems; Management Skills, associated with management; Technological Skills, which include knowledge and skills related to Artificial Intelligence, programming, Information and Communication Technologies (ICTs), computing, computer science, and data; Working with Others, which is associated with communication and leadership; Cognitive Skills, which, in addition to multidisciplinarity, includes decision-making among the most frequently mentioned specific competencies, as well as other competencies; and Specialized Machinery and Equipment Operation, which includes competencies related to drones.

Criteria Defined for the Organization and Selection of Competencies

Due to the large number of competencies identified across the literature review and field research, a set of criteria was established to support the selection and organization of the knowledge, skills, and attitudes that comprise the competency framework for Digital Agriculture (DA). The main criteria were:

- **Selection of competencies** primarily based on the frequency with which they were mentioned in the field research, followed by the frequency observed in the data collected from the literature review of scientific articles and from the occupational taxonomies and competency frameworks QBQ (Brazil, 2024, 2025), O*NET (United States, 2024, 2025), and ESCO (European Commission, 2024, 2025). The skills identified in the Future of Jobs Report 2025 (World Economic Forum, 2025) for the Agriculture, Forestry, and Fishing sector also supported the decision-making and competency selection process.
- **Organization of competencies** based on the competency granularity models adopted by the Global Skills Taxonomy (World Economic Forum, 2021), ESCO (European Commission, 2024, 2025), and QBQ (Brazil, 2024, 2025).
- **Selection of the words or expressions** used to represent knowledge, skills, and attitudes, taking into account the definition of each term and its correspondence with the concepts expressed by interviewees and focus group participants during the field research.
- **Use of simpler and more informal terms, words, expressions, and definitions** for competencies, with the aim of making the framework easier to understand for professionals from different specialties and other Digital Agriculture stakeholders.

Competency Framework for Professionals Working in Digital Agriculture

The competency framework for professionals working in Digital Agriculture (DA) is composed of 177 items organized into four levels of granularity. Figure 1 presents the four levels of detail—namely, categories, areas, competency families, and specific competencies—and indicates the number of associated items or competencies.

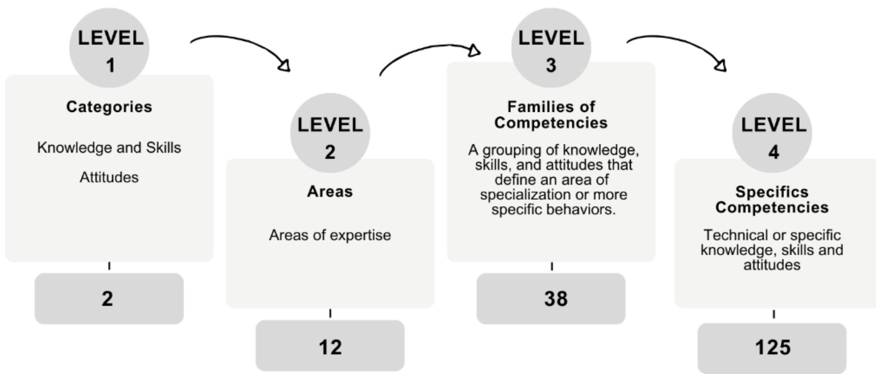

Figure 1. Levels of granularity of the Digital Agriculture competency framework

Figure 2 presents the first and second levels of granularity of the competency framework for professionals working in Digital Agriculture, namely the categories and competency areas.

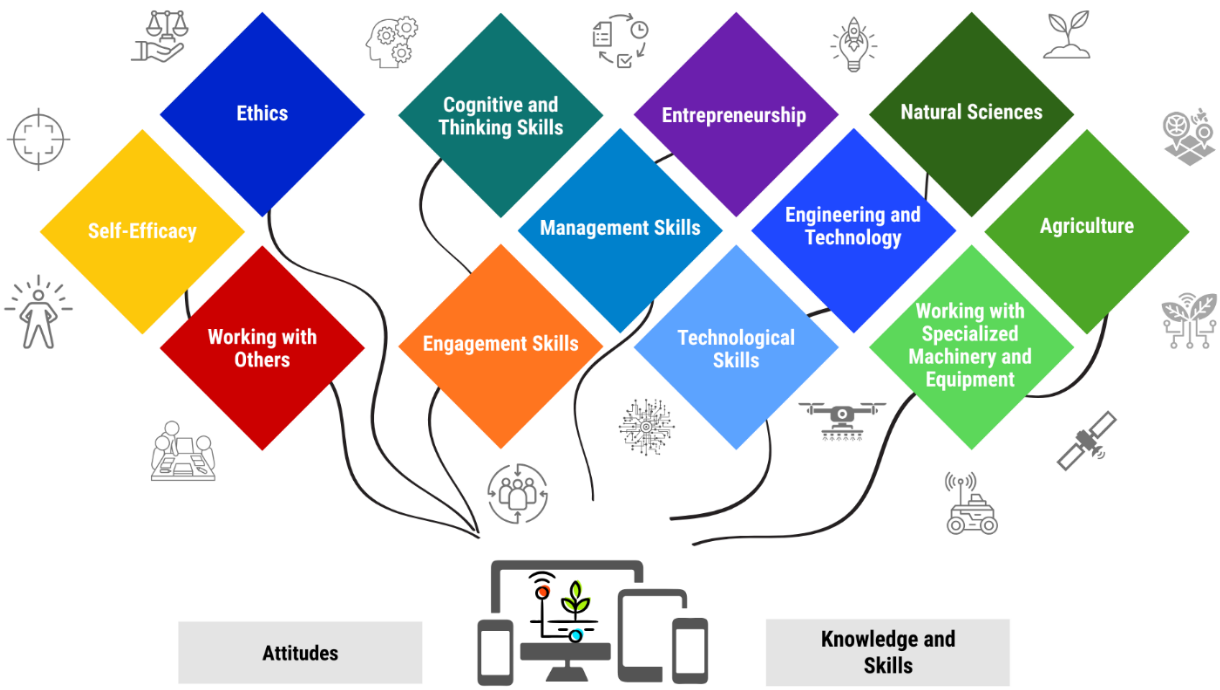

Figure 2. Competency framework for Digital Agriculture professionals – Levels One and Two

Table 7 describes the categories corresponding to Level One and the competency areas representing Level Two of the competency framework for professionals working in Digital Agriculture. Their conceptual descriptions are presented together with their respective data sources.

Table 7. Descriptions of Levels One and Two of the Digital Agriculture competency framework

Categories and Areas of Expertise	
Category	**Knowledge and Skills** Knowledge is composed of established concepts, facts and figures, ideas, and theories that underpin the understanding of a particular area or subject. Skills are defined as the ability to execute processes and use existing knowledge to achieve results. Source: European Union (2019).
Area	**Cognitive and Thinking Skills** Cognitive functioning refers to multiple mental abilities, including learning, thinking, reasoning, memorization, problem-solving, decision-making, and attention. Source: World Economic Forum (2024).
Area	**Engagement Skills**

	Ability to interact with clients, whether corporate or personal. Source: World Economic Forum (2024).
Area	**Management Skills** The ability to allocate resources efficiently and effectively and manage daily business activities to obtain value from physical or intangible assets. Source: World Economic Forum (2024).
Area	**Entrepreneurship** Taking advantage of opportunities and ideas, transforming them into value for others. The value created can be financial, cultural, or social. Source: Bacigalupo *et al.* (2016).
Area	**Technological Skills** Designing and using technology effectively. Source: World Economic Forum (2024).
Area	**Engineering and Technology** Knowledge of the practical application of engineering science and technology. Includes the application of principles, techniques, procedures, and equipment to the design and production of various goods and services. Source: United States (2025).
Area	**Natural Sciences** Branch of science that deals with the physical world.. Source: Natural sciences (2025).
Area	**Agriculture** The practice of cultivating the soil, growing crops, or raising livestock for human use, including the production of food, feed, fiber, fuel, or other useful products. Source: Agriculture (2025).
Area	**Working with Specialized Machines and Equipment** Controlling, operating, and monitoring vehicles, stationary and mobile machinery, instrumentation, and precision equipment. Source: European Commission (2025).
Category	**Atitudes** Attitudes are learned behaviors, traits of emotional intelligence, and beliefs that individuals demonstrate and that influence their approach to ideas, people, and situations.. Source: World Economic Forum (2021).
Area	**Self-efficacy** Controlling one's own thoughts, feelings, and actions. Source: World Economic Forum (2024).
Area	**Working with others** Emotionally intelligent behaviors that help a team complete tasks effectively, promoting cooperation, communication, respect, and mutual development. Source: World Economic Forum (2024).
Area	**Ethics** Ethical attitudes maintain awareness of the social and environmental impacts of personal and organizational actions, and can actively mitigate, prevent, and repair harmful impacts. Source: World Economic Forum (2024).

Note: elaborated by the authors.

Conclusion

The implementation of mixed data collection approaches was an essential strategy for developing the competency framework for professionals working in Digital Agriculture (DA). The literature review enabled the construction of a robust theoretical foundation based on the analysis of scientific articles retrieved from Scopus, Web of Science, and Google Scholar databases. In addition, data obtained from the ESCO, O*NET, QBQ, and Global Skills Taxonomy occupational taxonomies and competency frameworks were analyzed and combined with the competencies suggested in the Future of Jobs Report 2025 for the Agriculture, Forestry, and Fishing sector. The field research, conducted through semi-structured interviews and focus groups involving different Digital Agriculture stakeholders, made it possible to understand the diversity of perspectives regarding the knowledge, skills, and attitudes that are essential for Digital Agriculture, as well as the challenges and opportunities related to the education and training of professionals in this field.

The analysis of the empirical data revealed heterogeneity in the levels of detail of the competencies mentioned, with a significant prevalence of references to specific competencies. This aspect proved fundamental for structuring the competencies into four levels of detail, as the objective was to integrate as many common competencies as possible, identified through field research, whenever they were supported by data from the literature review.

The competency framework for professionals working in Digital Agriculture was developed around two competency categories—Knowledge and Skills, and Attitudes—which represent the first level of detail. The second level of granularity comprises 12 competency areas: Cognitive and Thinking Skills; Engagement Skills; Management Skills; Entrepreneurship; Technological Skills; Engineering and Technology; Natural Sciences; Agriculture; Working with Specialized Machines and Equipment; Self-efficacy; Working with Others; and Ethics. These competency areas are further subdivided into competency families and specific competencies. The framework developed as a result of this research is intended to serve as a starting point for sectors, organizations, and professionals to customize their own competency structures and reflect on the most appropriate pathways for acquiring or developing competencies that are essential for Digital Agriculture.

Future research may include the development of stakeholder-specific or occupation-specific competency frameworks for Digital Agriculture. Studies may also be conducted to define the level of proficiency required for each competency associated with a specific role. Reassessing the curricula of technical and university programs related to Digital Agriculture, in both public and private educational institutions, based on the competencies identified in this framework, represents a line of research that may support the education of new professionals and the upskilling of those already working in the field. Another avenue for future work is the development of training and professional development programs that encompass the integrated formation of the knowledge, skills, and attitudes required to work in Digital Agriculture.

Acknowledgments

This research is funded by the Research Incentive Plan – PIPEq of the Pontifical Catholic University of São Paulo (PUC-SP); by the National Council for Scientific and Technological Development – CNPq, Process Number: 408676/2021-3, and by the Coordination for the Improvement of Higher Education Personnel (Capes), Process Number: 88887.657910/2021-00.

References

Adel, A., Pullanagari, R., Alani, N. H. S., Al-Rawi, M., Fouzia, S., & Berger, B. (2023). Drones-of-the-future in Agriculture 5.0: Automation, integration, and optimisation. *Drones, 7*(11), 666.

Agriculture. (n.d.). In *Oxford Reference*. Oxford University Press.

Altamirano, A., & Amaral, N. (2020). *A skills taxonomy for LAC: Lessons learned and a roadmap for future users* (Technical Note IDB-TN-02072). Inter-American Development Bank.

Bolfe, É. L., et al. (2020). Precision and digital agriculture: Adoption of technologies and perception of Brazilian farmers. *Agriculture, 10*(12), 653.

Brandão, H. P. (2023). *Mapeamento de competências: Ferramentas, exercícios e aplicações em gestão de pessoas*. Atlas.

Brazil. Ministry of Labor and Employment. (2024). *Quadro Brasileiro de Qualificações (QBQ): Estrutura e fundamentos*. MTE.

Brazil. Ministry of Labor and Employment. (2025). *Quadro Brasileiro de Qualificações (QBQ): Estrutura e fundamentos*. MTE.

Carbone, P. P., Brandão, H. P., & Leite, J. B. D. (2006). *Gestão por competências e gestão do conhecimento*. Editora FGV.

Charatsari, C., et al. (2022). Farm advisors amid the transition to Agriculture 4.0: Professional identity, conceptions of the future and future-specific competencies. *Sociologia Ruralis, 62*(2), 335–362.

Enkhjav, T., & Davaasambuu, A. (2019). Industrial and agricultural 4.0: Competencies and skills. *Modern Science – Moderní věda, 6*, 76–86.

European Commission. (2020). *European skills agenda for sustainable competitiveness, social fairness and resilience*. European Commission.

European Commission. (2024). *ESCO: European Skills, Competences, Qualifications and Occupations*. European Commission.

European Commission. (2025). *ESCO: European Skills, Competences, Qualifications and Occupations*. European Commission.

European Union. (2019). *Key competences for lifelong learning*. Publications Office of the European Union.

FAO. (2022). *The future of food and agriculture: Drivers and triggers for transformation* (The Future of Food and Agriculture No. 3). FAO.

Hasan, K., Aftah, R. M., & Syakban, M. N. (2022). Digital skills in the optimization of agricultural technology among millennials: A descriptive study on agricultural students at Malikussaleh University. In *Proceedings of the International Conference on Social Science, Political Science, and Humanities (ICoSPOLHUM)* (p. 00007).

Manzini, E. J. (2003). Considerações sobre a elaboração de roteiro para entrevista semiestruturada. In *Colóquios sobre pesquisa em educação especial*. Eduel.

Massruhá, S. M. F. S., Leite, M. A. L., Oliveira, S. D. M., Meira, C. A. A., Luchiari Junior, A., & Bolfe, É. L. (2020). *Agricultura digital: Pesquisa, desenvolvimento e inovação nas cadeias produtivas*.

Mattar, J., & Ramos, D. K. (2021). *Metodologia da pesquisa em educação: Abordagens qualitativas, quantitativas e mistas*. Grupo Almedina.

Molin, J. P., et al. (2020). Precision agriculture and the digital contributions for site-specific management of the fields. *Revista Ciência Agronômica, 51*.

Natural sciences. (n.d.). In *Oxford Learner's Dictionaries*. Oxford University Press.

Okoli, C. (2019). Guia para realizar uma revisão sistemática da literatura (D. W. A. Duarte & J. Mattar, Trans.). *EaD em Foco, 9*(1).

Rossi Junior, J. L., & Doyle, M. (2023). *Desafios de desenvolvimento do país: Rota para um crescimento sustentável e inclusivo*. Inter-American Development Bank.

Rubin, H. J., & Rubin, I. S. (2011). *Qualitative interviewing: The art of hearing data*. Sage.

Saldaña, J. (2013). *The coding manual for qualitative researchers* (2nd ed.). Sage.

Silveira, F. da, Landaverde, R., & Barbedo, J. G. A. (2026). Drivers of Agriculture 4.0 technologies in the agri-food system: A systematic literature review and directions for future research. *Computers and Electronics in Agriculture*, *243*, 111351.

Silveira, F. da, Lermen, F. H., & Amaral, F. G. (2021). An overview of Agriculture 4.0 development: Systematic review of descriptions, technologies, barriers, advantages, and disadvantages. *Computers and Electronics in Agriculture, 189*, 106405.

Silveira, F. da, Silva, S. L. C. da, Machado, F. M., Barbedo, J. G. A., & Amaral, F. G. (2023). Farmers' perception of the barriers that hinder the implementation of agriculture 4.0. *Agricultural Systems*, *208*, 103656.

Sun, Y., Miao, Y., Xie, Z., & Wu, R. (2022). Drivers and barriers to digital transformation in agriculture: An evolutionary game analysis based on the experience of China. *Journal of Cleaner Production, 355*, 131760.

United States Department of Labor. (2024). *O*NET Online: Occupational Information Network*. Employment and Training Administration.

United States Department of Labor. (2025). *O*NET Online: Occupational Information Network*. Employment and Training Administration.

Weersink, A., Fraser, E., Pannell, D., Duncan, E., & Rotz, S. (2018). Opportunities and challenges for big data in agricultural and environmental analysis. *Annual Review of Resource Economics, 10*, 19–37.

Winarno, K., et al. (2025). Unlocking agricultural mechanisation potential in Indonesia: Barriers, drivers, and pathways for sustainable agri-food systems. *Agricultural Systems, 226*, 104305.

World Economic Forum. (2021). *Building a common language for skills at work: A global taxonomy*. World Economic Forum.

World Economic Forum. (2024). *Global Skills Taxonomy: A common language for the world of work*. World Economic Forum.

World Economic Forum. (2025). *Future of Jobs Report 2025: Insight report*. World Economic Forum.