Design Thinking Applied to the Internet of Things

A Project on Technological Innovation in Agriculture and Food Processing

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***Abstract*— Agriculture experiences rapid changes due to advances in technology. The introduction of mechanical equipment caused the first agricultural revolution. Agriculture is moving into the information age, where data are collected and analyzed to improve production and quality. Internet of Things (IoT) plays an essential role in innovative developments. This paper introduces the use of Design Thinking (DT) to create innovative solutions for agriculture and food processing. DT is well suited for multidisciplinary teams. An ongoing project is presented where agriculture and technology students meet farmers and other stakeholders in a summer school setting to learn from each other and innovate together. DT is used as the framework for innovation and co-creation.**

Keywords-design thinking; agriculture; Internet of Things; IoT; innovation.

I. Introduction

In 2021, Lucian Blaga University of Sibiu, Romania, and the University of South-Eastern Norway won a grant for a project to exploit the Internet of Things (IoT) within agriculture and food processing. This paper discusses the ideas behind the project and its practical implementation. The main assumptions are:

- IoT has a great potential to improve agriculture and food processing.
- The design process itself is essential for innovation to take place.
- The involvement of different stakeholders in the design process is necessary to unleash the potential of IoT technology.
- Innovation is achieved by bringing teachers and students from agriculture, food processing, engineering, and computer science together in a workshop with farmers and IoT specialists.

The rest of the paper is organized as follows: Section II discusses the importance of technological innovations in agriculture. Section III takes a closer look at the IoT. Section IV describes potential areas of IoT applications in agriculture. Section V discusses the design process and methodology. Section VI describes the practical implementation of the project as two summer schools focusing on IoT in agriculture. Section VII discusses the practical implications of the project, while Section VIII provides a conclusion.

II. Agricultural Developments

Agriculture is essential for society because it represents a source of livelihood and raw materials for industry, ensures food and fodder supply for people and animals, and contributes to national revenue, economic development, and international trade. Agriculture provides many employment opportunities, such as farm work, building irrigation and drainage systems, transporting goods, and retailing products.

Through the European Horizon 2020 research program, the European Union acknowledges the importance of focused research and testing of the IoT to support the development and take-up of the technology in different economic sectors (industry, agriculture, logistics, transport) [1]. On April 9th, 2019, EU Member States signed the declaration of cooperation on "A smart and sustainable digital future for European agriculture and rural areas" [2]. The declaration acknowledges the potential of digital technologies and proposes actions for the digitalization of agriculture in Europe. The use of technology substantially impacts agricultural production, and the introduction of automation, robotics, IoT, knowledge-based systems, and artificial intelligence facilitates further improvements in farming practice [3]. New technology impacts the whole agrarian ecosystem and provides new opportunities for monitoring and control, ensuring the safety of agricultural food products.

Agriculture is moving into the information age, where data are collected and analyzed to improve production and quality. IoT plays an essential role in innovative developments. As the global population increases, smart farming and precision agriculture [4] are crucial for a sustainable future. Smart farming and precision agriculture reduce human intervention and increase production quantities.

Specifically, IoT systems and drones are used in applications like precision agriculture, crop irrigation planning, plant disease detection, and soil texture mapping. It is also used for crop maturity monitoring to correctly assess optimal harvest time and monitoring growth to plan the necessary equipment for harvesting, transporting, and storing the production.

Images collected with drones can lead to a correct estimation of biomass or identify fruit diseases. Automated harvesting using mobile robots and robotic arms can reduce human labor and increase productivity. The development of computer engineering and information technology created the premises of a data-driven society. Data has become a key element in modern agriculture (Agriculture 4.0 [5]), helping producers make critical decisions [6].

IoT devices equipped with sensors can collect data and forward the data to cloud-based solutions using artificial intelligence techniques to maximize productivity and improve sustainability.

Sustainable agriculture is not restricted to the EU; it is global. In this sense, the United Nations (UN) [7] targets the following sustainable development goals (see Table 1).

TABLE I. UN SUSTAINABILITY GOALS RELATED TO AGRICULTURE

Goal	Description
Zero hunger	Implementing sustainable food production systems and resilient practices in agriculture, especially for developing countries, such that by 2030, hunger and malnutrition will end worldwide.
Clean water and sanitation	International cooperation for protecting wetlands and rivers and sharing water treatment technologies to ensure clean water and sanitation of the planet's population in the conditions of population growth and climate changes.
Industry, innovation, and infrastructure	Increasing investment in scientific research, innovation, and infrastructure to reduce the digital gap (digital technologies and Internet connectivity) between countries and promote sustainable development in industry and agriculture.
Responsible consumption and production	More efficient management of natural resources and removal of toxic waste, halving global food waste per capita, waste recycling, and education toward more responsible consumption.
Life on land	Preserving and restoring the use of terrestrial ecosystems such as forests, wetlands, deserts, and mountains, stopping the biodiversity loss by 2030, affected by population growth, industrialization, and transition to cities and climate changes.

III. INTERNET-OF-THINGS

IoT refers to devices exchanging data with other devices and systems through the Internet. IoT is expected to offer advanced connectivity of devices, systems, and services beyond Machine-to-Machine (M2M) communications and covers various protocols, domains, and applications. In 2014, the number of IoT devices was estimated to be approximately 19.7 billion and is expected to grow to 95.5 billion in 2025 [8].

Figure 1 shows a model of a typical IoT device with a microcontroller, sensors, actuators, and communication technology.

IoT systems are multilayer architectures [9]. Figure 2 shows a simple architectural model with an application layer and two sublayers: the perception sublayer and the network sublayer.

The sensors (perception sublayer) collect data from the outside world. A sensor transforms the detection or measurement of a physical property into an electric signal. Physical properties include temperature, humidity, moisture, barometric pressure, gases, movement, distance, light, voltage, and current.

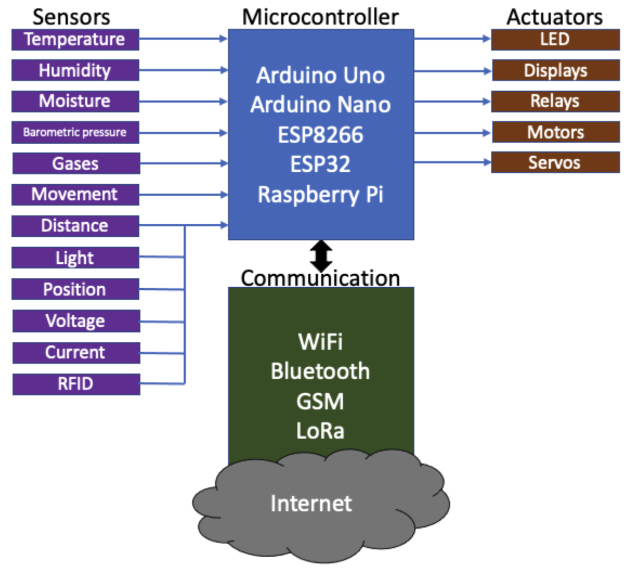

Figure 1. Typical IoT device.

More advanced sensors may read RFID tags or positions from satellites through the Global Positioning System (GPS).

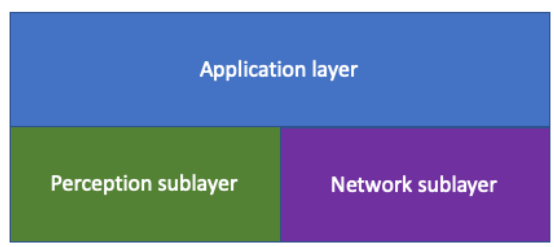

Figure 2. IoT basic architecture.

Actuators may be simple output devices such as light-emitting diodes (LEDs), displays, motors, and servos. All kinds of electric units can be controlled through relays. The microcontroller processes the inputs from sensors and controls the actuators. An IoT device also needs communication capabilities to communicate through the Internet. Communication (the network sublayer) can be wired or wireless. Several technologies exist for wireless communication, such as WiFi, Bluetooth, LoRa, NFC, and GSM [10].

Data collected by an IoT device can be used to control its surroundings and sent for further processing through the Internet. A typical application is shown in Figure 3, where a temperature sensor is used to control a heating element. The program code in the application layer reads the temperature and decides whether the heating element should be turned on or off. At the same time, the temperature data is sent to a decision support system that may influence when to turn the heating element on and off to optimize energy use.

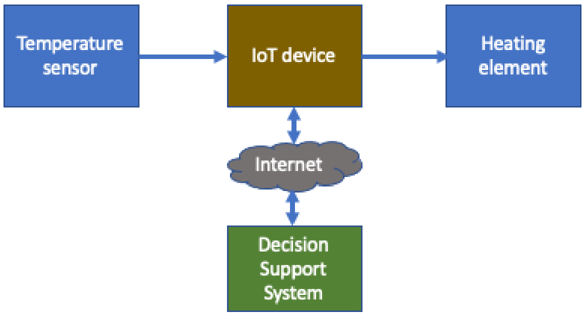

Figure 3. An example of an IoT application.

IV. IOT IN AGRICULTURE

Agriculture is a promising field for the use of IoT. The agricultural processes rely on collecting data, analyzing the data, and using the results to create optimal conditions for growth. A typical example is a greenhouse where optimizing temperature, humidity, lighting, CO_2, and fertilizers can significantly increase the yield. Table II and Table III show examples of how IoT solutions can be used for crops and livestock management.

TABLE II. IOT SOLUTIONS FOR CROPS MANAGEMENT

Solution	Description
Environmental monitoring	Collect data about environmental variables (temperature, humidity, moisture, barometric pressure). Data is used for automated decision-making and forecasting. Environmental monitoring may be done by a network of interconnected sensor stations or using land and aerial drones.
Crop measurement	Measuring when the crop reaches a certain height or size. Used to optimize harvesting according to requirements set by customers; rot detection.
Irrigation	Use of sensor data and machine learning algorithms to decide on irrigation. Reduce unnecessary spills of water.
Fertilizing	Use of data to optimize the use of fertilizer. Reduce the amount of fertilizer used.
Pest control	Detecting pests, e.g., through discoloration, and minimizing the use of pesticides by targeting only crops with specific needs.
Decision-making	Deciding when to sow and harvest based on updated measurements and forecasting.
Automation	Automating machinery for sowing and harvesting. Possibilities for detecting malfunctions and suggesting preventive maintenance

IoT in agriculture contributes to improved quality and efficiency and is essential for value creation for farmers.

The examples presented show how IoT can be utilized on farms. However, IoT also has a role in the whole value chain, from raw materials to the end customer. Table IV lists some opportunities for using IoT in the agricultural value chain.

TABLE III. IOT SOLUTIONS FOR LIVESTOCK MANAGEMENT

Solution	Description
Monitoring	Monitor livestock for health problems, find the right moment for insemination using birthing sensors or check for mastitis signs. It can also monitor and increase the quality of milk and wool.
Feeding	Optimize livestock feeding by mixing combinations of food and feeding at optimal cycles.
Control/ logistics	Keep track of livestock locations using RFID and GPS tracking devices. Control animals by virtual fences (*Geofences*). It saves physical fences and reduces the need for maintenance. Virtual fences also improve human access to nature.
Automation	Robots can take care of milking and harvesting wool.

Recent approaches combine IoT and blockchain technology with smart agriculture. Blockchains and smart contracts can improve the logistics and traceability of agricultural products [11]. With increased focus on product origins and food safety, small IoT devices may follow the products from the farm to the consumer. Such devices will keep track of the supply chain and detect anomalies in storage temperatures, etc. [12].

TABLE IV. IOT IN THE AGRICULTURAL VALUE CHAIN

Solution	Description
Origin tracking	Use intelligent tags (RFID, NFC) to track deliveries through the value chain.
Quality tracking	Smart IoT devices can keep track of environmental conditions during transport and storage.

Precision agriculture-specific approaches combine IoT with big data and decision support systems, combined with artificial intelligence prediction techniques for efficient control of farm irrigation valves and soil moisture prediction [13].

A practical example of the innovative use of IoT in agriculture is the early detection of soft rot in potato storage bins [14]. Soft rot spreads on contact, and if detected early, rotten potatoes can be removed from the container and save the rest of the batch. The farmer can be alerted by an app connected to the Internet.

V. DESIGN THINKING

This section describes Design Thinking (DT). DT was first introduced worldwide in 2005 at Stanford University in Palo Alto, USA. In Europe, DT was adopted in 2007 by the Hasso Plattner Institute in Potsdam, Germany [15]. DT contemplates human needs while considering both a technical perspective (technological feasibility) and an economic perspective (economic viability).

DT is based on the creative power of teamwork, collaboration, innovation, and interdisciplinary teams. Implementing this concept involves an iterative process based on the following states: understanding, observation, defining a point of view, design, developing a prototype, and testing/validation (see Figure 4).

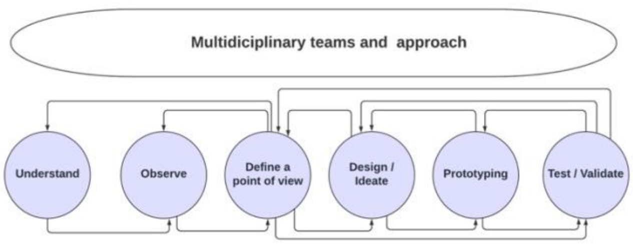

Figure 4. Design Thinking: An Iterative but not Linear Process.

The authors have experience using DT in workshops and hackathons and see it as a feasible methodology to enhance innovation in agriculture. A bibliometric analysis was performed to investigate the influence of DT on agriculture. The period examined was from 2004 to 2021. Only 36 articles containing the phrases "design thinking" + "agriculture" + "innovation" in the "Title," "Abstract," or "Keywords" or appeared at least ten times in the article's content were selected.

VOSviewer is a software tool for constructing and visualizing bibliometric networks using advanced clustering and visualization techniques to show the relationships between keywords characterizing articles from the Scopus database.

VOSviewer enabled us to determine how often each item occurred within the network and how often the elements were cited together. The use of the software also facilitated combining the analyzed data set into clusters which were then marked out on the map in different colors.

The bibliometric study shows that very few researchers have considered DT for innovation in agriculture. Four clusters, drawn in different colors, are visible in the chart (see Figure 8 at the end of the paper). The first cluster (red) focuses on the system and design thinking related to company, business models, value, collaboration, diversity, application, and sustainability. The keywords belonging to the second cluster (yellow) gravitate around innovation and link innovation with keywords like approach, knowledge, idea, research, use, policy, process, and decision. The third cluster (blue) reflects the entrepreneurship approach learned in university and focuses on real farmers' challenges and needs, (case) studies, and their role for economic profit and animal welfare. Finally, the fourth cluster (green) focuses on sustainable agricultural developments based on science and engineering. Table V shows the clustering of keywords in the 36 articles found.

For example, DT in building agricultural equipment aims to understand the needs of the customers, farmers, workers, and machine operators, to convert the ideas through a useable approach to develop a problem-solving activity or machine. A challenge for integrating DT in agriculture consists of bringing the farmers into the process of designing solutions. Technology innovation has become an important trend in the development of various sectors. Compared with manufacturing and high-tech industries, agriculture typically pays more attention to the conditions of farm sites than technology. The successful growth and transformation of the agriculture industry require a deep understanding of local social contexts and farmers' habits.

TABLE V. CLUSTERS GENERATED BY THE BIBLIOMETRIC STUDY

Cluster #	Number of keywords	Important (relevant) Keywords
1.	13	design thinking with relations to problem, model, system, company, business, industry, technology, collaboration, value, diversity, application and sustainability
2.	10	innovation, approach, research, policy, process, decision, knowledge, idea, use, evidence
3.	10	entrepreneurship, university, challenge, (case) study, paper, role, farmer, need, animal welfare
4.	10	agriculture, (sustainable) development, (agricultural) engineering, project, science, integration, implementation, world

The intention of young farmers to employ innovative technologies depends on the perceived usefulness and the perceived ease of use of IoT devices. The reputation of system suppliers and users' trust in software and hardware suppliers affect users' intention to adopt innovative technologies. Young farmers' intention to adopt smart sensor technology increases with the reputation of IoT suppliers, field-level information analysis quality, and individual privacy security [16].

DT may innovate agriculture by combining expertise from multiple perspectives and disciplines, primarily computer science and agriculture/food processing, stimulating collaborative work to facilitate the deployment of digital technologies in agriculture. More precisely, the innovation is based on transferring knowledge and skills from the computer science domain to the agriculture/food processing domain and vice versa.

The farmers (who may have basic knowledge of digital technologies but almost no knowledge of IoT systems, artificial intelligence, robotics, or drones) should see possible opportunities in agriculture provided by digitalization. The engineers need to understand agriculture's practical problems and challenges to design and implement proper solutions [17].

VI. ENTREPRENEURIAL AGRICULTURE AND EDUCATION

As shown in Figure 5, DT connects technology with the needs of the market or the society. In this context, the technology is IoT, while the market is the agricultural sector. Research is done from the initial idea, and a product or process is designed and developed. A prototype is made and tested before continuing with manufacturing, followed by marketing and sales.

The idea generation requires knowledge of both technology and agriculture. IoT experts need to share their knowledge with farmers and vice versa. Most farmers are unaware of the opportunities provided by IoT. At the same time, engineers often lack the domain knowledge to create products and processes that create high value for the agricultural sector.

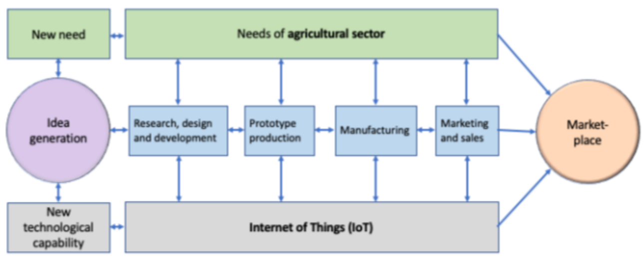

Figure 5. Design Thinking process for IoT in agriculture.

Usually, in universities, engineering and agriculture are separate study programs within their respective faculties. Agriculture students do not learn about IoT, and engineering students do not study agriculture. Therefore, a viable approach would be to create multidisciplinary activities where students from both programs meet, learn from each other, and co-create new products and processes. Such activities could be:

- Cross-disciplinary course modules where students work together to identify and solve real problems in agriculture by using IoT.
- Shorter "Hackathon" style events where students do the same, but within a strict timeframe, e.g., 24 or 48 hours.
- Summer schools where students do the same, but within a longer timeframe, e.g., two weeks.

The students will bring their respective backgrounds, but they also need training in DT. The DT process is the catalyzer for innovation and will be the common ground for the students. The DT process is a good framework for co-creation activities.

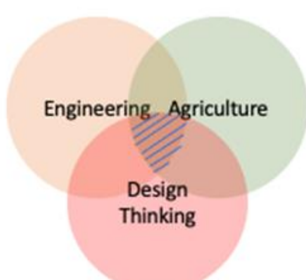

Figure 6. Skillset.

Figure 6 shows the different skills required to contribute to IoT in agriculture.

Creating value for the customer (farmer) should be the primary goal of IoT products and services. The agriculture sector includes the whole value chain from the farmer to the end consumer. Figure 7 presents the different elements of the agricultural value chain. The input is seeds, fertilizer, water, fodder, etc. The production results are grain, vegetables, fruits, dairy products, meat, etc. The products must be cleaned, graded, and packed before they are either distributed to the retail market or refined into more complex products.

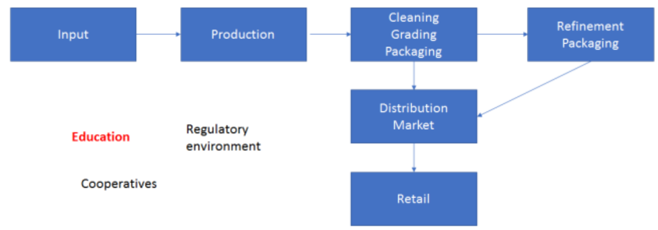

Figure 7. Agricultural value chain (crops and livestock).

Education, stakeholder cooperation, and the regulatory environment supports this value chain. IoT can be integrated at any stage of this agricultural value chain to digitalize the process, optimization, tracking, and quality assurance. As documented earlier, developments in agriculture are high on the political agenda and closely connected to the United Nations sustainability goals. Developments within agriculture can potentially revolutionize how the global population can be fed.

VII. Conclusion

Agriculture is essential in achieving the sustainability goals set by the United Nations, in particular. The imbalance regarding the agriculture performance of world countries must be reduced only by changing the agricultural landscape through new technologies or new methodologies and cross-fertilizing different scientific and educational sectors.

This paper has discussed the use of IoT in agriculture. DT has been suggested as a viable methodology to achieve innovation.

As already mentioned, this paper reports on an ongoing project to examine and promote IoT use in agriculture. An essential part of the project is two editions of a summer school, one in Norway and one in Romania, where technology students will work with agriculture and food processing students to innovate together. The summer schools will be on farms where students explore real problems in an authentic setting.

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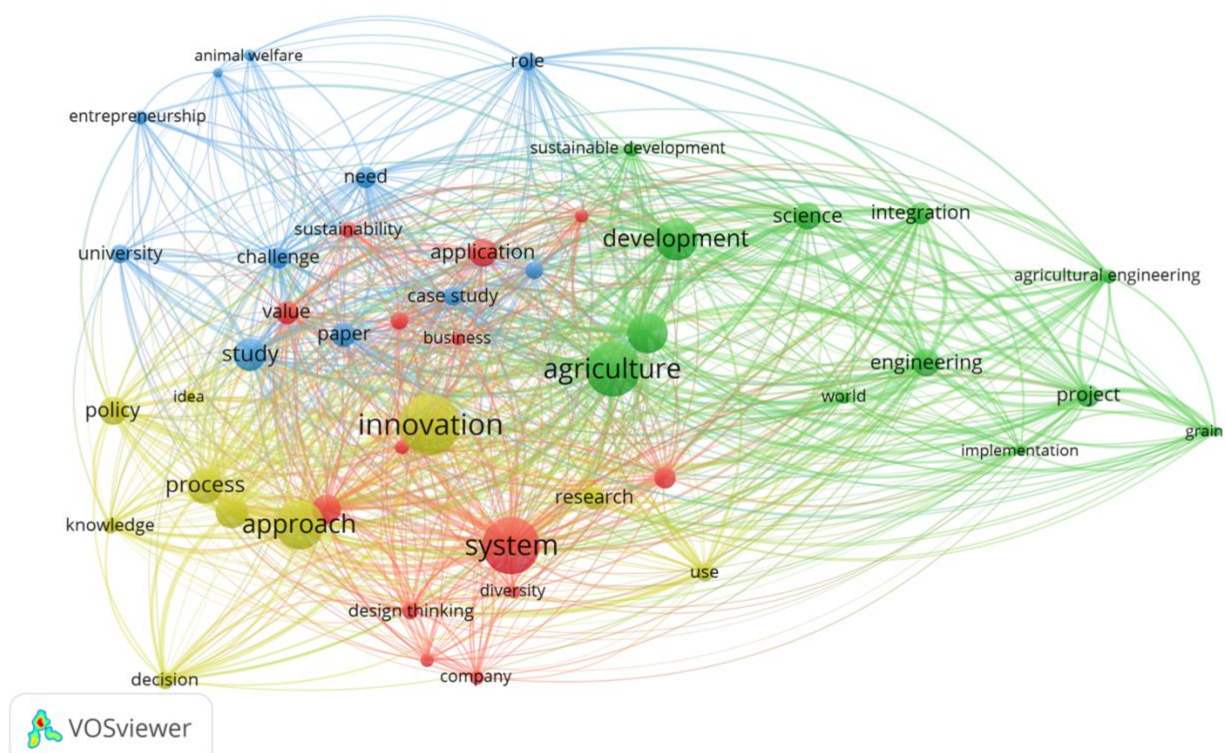

Figure 8. Keyword clusters from VOSviewer.