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Article

# Opportunities of Digital Transformation in Post-Harvest Activities: A Single Case Study of an Engineering Solutions Provider

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**Abstract:** The purpose of this article is to identify opportunities that digital transformation in post-harvest activities offers to an engineering solution provider. The research method is a simple case study. The object is a company based in southern Brazil that provides engineering-integrated digital solutions to grain producers, including products and services. The specific objectives are to describe the company's digital products and services, identify opportunities and players, and discuss how players can take advantage of opportunities owing to business process digitalization. The main results include separating products into three technological layers and identifying five types of opportunities (financing, commercialization, operation, logistics, traceability, and insurance), eight types of players, and the main opportunities for each player. The most significant opportunities are risk reduction in insurance contracts, improvement in grain quality, increments in food safety, and accurate information on grain movements. The main implication of the study is that grain producers and other players can explore opportunities, and solution providers can evolve toward complete digitalization by integrating service into the current offerings of post-harvest engineering solutions.

**Keywords:** digital transformation; agribusiness; post-harvest; food safety; food quality; engineering solutions



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## 1. Introduction

The world population should rise from 6.9 billion in 2010 to more than 9.4 billion in 2050 [1]. At the same time the population grows, the global availability of arable land per capita decreases. While in 1950 there was approximately 0.52 hectares per capita, by 2050, this figure will decrease to 0.17 hectares [2]. Furthermore, aggravated by climate change, the per capita demand for water has also risen, completing a picture and highlighting the need for more productivity in agricultural production systems [3]. The use of digital technologies can contribute to increasing such productivity [4]. The literature offers many cases in developed and developing countries that support the success of digital transformation in agri-food system management [5].

Agriculture, specifically the production of grains and cereals, plays an essential role in producing food for human and animal consumption. The literature estimates that 1 kg of beef, pork, and poultry production requires 7, 4, and 2 kg of grains, respectively [6]. The interest of the authors of this article includes the so-called grain post-harvest activities.

Post-harvest activities include companies from the metal-mechanical industry that provide engineering solutions for the sector. Such companies deliver solutions to maintain the quality of grains or cereals after harvesting until used by the agro-industry, retailers, and final consumers [7]. For vendors of post-harvest supporting equipment, digital transformation is an opportunity for a rapid evolution in business models. The income of such companies has depended almost exclusively on the sale of physical goods, such as grain silos, conveyors, storage facilities, or dryers. Currently, those companies, based on digital technologies, also offer engineering solutions that incorporate services into the current portfolio of products [8]. Nonetheless, such companies should still understand how digital transformation influences their business models. It is necessary to identify what capabilities to develop as well as the main opportunities digital transformation may convey to provide new sources of revenue [9]. Identifying such opportunities is the research gap this article aims to bridge.

The purpose of this article is to identify opportunities that digital transformation in post-harvest activities offers to an engineering solution provider. The research method is a simple case study. The object is a company based in southern Brazil that provides engineering-integrated digital solutions to grain producers, integrating products and services. The specific objectives are to describe the company's digital products and services, identify the main types of opportunities and the interested players, and discuss how the players can benefit from opportunities. The main expected implication is to offer post-harvest solutions vendors a guideline to explore new opportunities and change their business models by integrating digital services and physical goods. The structure of the rest of this article is as follows. Sections 2–5 contain the literature review, methodology and results, types of opportunities, and final remarks.

## 2. Literature Review

### 2.1. Digital Technologies

Cutting-edge digital technologies merge information, computing, communication, and connectivity to disrupt business models [10] and reshape relationships within business networks [11]. The key characteristic of digital technologies lies in their ability to integrate digital capabilities into objects that were previously purely physical, like equipment, appliances, or vehicles [12]. Furthermore, digital technologies introduce advanced functionalities, such as autonomy and tracking capabilities, which drastically enhance performance [13]. In essence, digital innovation initiatives blend digital and physical elements within a layered modular architecture, yielding novel products accompanied by unprecedented services that cater to the end user's needs [14]. Such initiatives often lead to profound alterations in products [15], organizational structures, and process management [16]. Ultimately, a sociotechnical digital transformation unfolds in social and institutional contexts, rendering digital technologies integral to the infrastructure [17].

Digital innovation possesses distinctive traits, including re-programmability, data homogenization, and a self-referential nature. Layered modular architectures form the organizing logic behind digitized products, allowing them to function simultaneously as both products and platforms. An exemplary instance appears in devices reliant on cloud storage. The layered architecture empowers companies to compete in specific layers, such as equipment, while fostering collaboration in others, such as services [18], aligning with the established concept of coopetition [19]. The convergence of digital technologies is apparent through interconnected yet distinct elements like artifacts, platforms, software, and databases that leverage the same digital infrastructure [14].

By embedding digital artifacts into physical devices, information can be stored, enabling programmability, addressability, communication, traceability, and association [20]. The separation of form and function enables artifacts to swiftly acquire new features at relatively insignificant costs. Digital infrastructures, such as social media, data analytics, cloud computing, and 3D printing, offer tools for rapid scalability [21] and international expansion [22]. In recent years, trailblazing pioneers like Google, Amazon, and Meta have risen to prominence, spearheading a new era of platform-based competition [23,24].

Prominent digital companies and their platforms have expedited the process of digitalization in the business realm. A seminal article from 1991 [25] introduced the concept of a pervasive computing environment, envisioning a future where revolutionary technologies seamlessly blend into everyday life, becoming indistinguishable from commonplace activities, like reading a book. A decade later, a pivotal study [26] predicted the proliferation of ubiquitous computing as mobile computing merged with pervasive computing, which integrates natural movements and interactions within physical and social environments. Subsequently, digitalization emerged as the foundation for immersive experiential computing, recognized as a sociotechnical process [17]. This process leverages advancements in digital infrastructures to analyze, interpret, and shape transformations within social and institutional contexts. In essence, digitalization is increasingly regarded as an entrepreneurial journey, wherein new business models undermine existing advantages, giving rise to more valuable or rapidly growing companies [14,15,18,20,21].

### 2.2. Digital Transformation in Companies

Digital transformation serves as a catalyst for companies to engage in experimentation and develop new business models [27]. Its impact can be far-reaching, transforming entire industries (e.g., passenger transport and accommodation), unifying products and services (books and document copying), spawning new businesses (cargo tracking), or presenting novel value propositions (e-commerce offering speed, affordability, and personalized delivery) [28]. In certain traditional sectors, digital transformation becomes imperative to safeguard established advantages [29–31]. It differs from other forms of strategic evolution primarily due to the rapid pace of change [23,32]. As digital transformation unfolds, it introduces heightened volatility, complexity, and uncertainty, necessitating adjustments in business models, organizational structures, and processes [33–35]. Digitalization opens opportunities for customer interaction, often leading to unforeseen innovations in business models [36–39].

Organizations equipped with transformative capabilities typically foster agile and entrepreneurial mindsets, emphasizing external networking [40]. Transformative capabilities support strategic renewal processes that involve adapting assets and structures to ensure responsiveness in swiftly changing digital environments [41,42]. Digital transformation presents challenging trade-offs, such as building innovation capabilities while preserving existing products, innovating not only products but also processes; balancing conflicts involving customers, employees, and suppliers; and establishing governance structures that ensure flexibility and control simultaneously [32]. For instance, in e-commerce, buyers and suppliers engage in online commercial transactions [43], creating a wealth of options and new expectations that prompt companies to reassess or augment their transactional value propositions [44–48].

Digital technologies disrupt the traditional logic of business models by elevating customer expectations for complementary products or services [47,49–51]. In response to customer demands, many internet-based businesses prioritize value creation through exceptional customer service over immediate profit capture, occasionally leading to flawed business models [24]. Consequently, established companies often encounter significant barriers to business model innovation that can impede their journey toward digitalization [29,36,50,52–57].

A business model encompasses a company's mechanisms for creating, delivering, and capturing value [47], encompassing strategic priorities, such as cost, revenue, and profit [58]. Innovation-based business models may incorporate elements, such as learning [52], shifts in management approaches [59], evolution [60], replication [38], reconfiguration [61], modularization, scalability [62], and digital transformation [36]. Certain business contexts, such as agri-food supply chains, require considerations for sustainability, including eco-design, where the business model targets not only financial performance but also environmental impact [63].

Difficulties in implementing innovation-based models are not uncommon. One reason is the belief that standard targets, such as profit margins or revenues, remain stable and can be pursued until achieved. When targets are not met, the common perception is that more effort needs to be invested [64,65]. However, in innovation-driven markets, new alternatives can swiftly disrupt performance parameters, for better or worse, thereby posing risks to even well-established business plans [44,51]. Another challenge arises from the trade-offs that emerge over time between static and dynamic models, necessitating more agile methods and monitoring of additional control variables [56,66]. An illustrative example of a model based on trade-offs is the servitization model, where a product company offers an associated service. Often, to ensure long-term service sales, the product must be sold under less favorable conditions, introducing a trade-off between the product and service [64,67]. This trade-off is commonly observed among providers of post-harvesting engineering solutions. Path dependency represents another barrier to innovation-based business models, as successful models from the past tend to be perpetuated [68,69]. However, exogenous shocks to performance can help balance the endogenous dependence on models that have previously been effective but are currently approaching exhaustion [70]. Disruptive business models may be deemed unlikely for certain companies [71], as they prefer incremental digitalization over disruptive modifications to existing activities [53,72,73].

The digital transformation of the business model necessitates a convergence of corporate and business unit models, requiring interdependent decision making [36,56]. To manage strategic complexity, companies often rely on previous experiences rather than entirely new approaches [70]. This decision-making process gives rise to conflicting demands, necessitating a delicate balance between agility and stability [69], certainty and uncertainty [74], or short- and long-term benefits [52]. In some cases, companies adopt a rational approach by addressing challenges in successive stages. They fully overcome one challenge before confronting a contradictory one, as exemplified by product servitization. Once the product-based business model is firmly established (low uncertainty), the company introduces the service component (high uncertainty). Subsequently, the focus may shift back to refining the product and so on, as the process continues.

### *2.3. Enabling Technologies for Digital Transformation in Post-Harvesting Activities*

Digital transformation processes must rely on integrating single digital technologies, encompassing the automation of processes and intelligent interconnections of machines. The integration results in cyber–physical systems. Such production systems are simultaneously physical, providing a flow of physical material, and logic, performing supervisory and control tasks [75]. Many recent authors have listed and analyzed the most relevant technologies supporting digital transformation processes, the so-called enabling technologies [76]. Among recent authors, relying on updated references, [77] cite automation (AUT), cyber–physical systems (CPS), big data analysis (BGA), radio frequency identification (RFID), cloud computing (CC), internet of things (IoT), additive manufacturing (AM), virtual reality and augmented reality (VRAR), and simulation (SIM) as enabling technologies for digital transformation in engineering solutions for primary activities.

Enabling technologies can contribute in different ways to post-harvest engineering solutions. AUT and CSF mainly help to reduce variability in processes [78]. The BDA mainly helps to develop models and find new behavior patterns for key variables in decision-making processes. CC mainly helps monitor the physical equipment's life-cycle behavior [79]. RFID mainly improves reliability in logistical operations, especially transportation [80]. The IoT helps to improve flexibility in key post-harvest processes, such as transportation and warehousing [81]. AM mainly assists in reducing material losses in machinery design and promotes reverse logistics activities, mainly managing shavings and leftovers produced by equipment manufacturers [82]. VRAR helps develop an eco-design and servitization principle: improving the performance of a product by incorporating environmental concerns and associated services [63]. Finally, SIM can help reduce the likelihood of making wrong choices in decision-making processes, including sales and purchases processes [83].

## 3. Results

### *3.1. Methodology*

The research strategy was a single case study. The object of study was a Brazilian company that provides engineering solutions for post-harvest activities. The primary research technique was non-participant direct observation, in which the researchers directly monitored the main activities in real time without interfering with their results.

The study included the following steps:

(i) The researchers collected and studied related documents issued by the engineering solution provider company;
(ii) The researchers took guided tours of the company's facilities and two nearby customer installations, accompanied by company practitioners;
(iii) The researchers interviewed three portfolio managers of the company;
(iv) In a final meeting, one of the researchers presented the notes to the managers, who eventually amended, adjusted, and finally confirmed the findings, ensuring reliability.

This study does not encompass losses quantification; instead, it solely focuses on describing potential opportunities that may be viable for future innovation initiatives. Owing to the use of a single case study strategy, the findings do not aim at providing external validity, meaning that the findings are only expected to be valid within the research scope. For broader external validity, future research should encompass the entire industry rather than focusing on a single company. The final meeting with the participants, during which they had the opportunity to review and amend certain aspects of the findings, enhances the internal validity and reliability of the study. This research is exploratory and qualitative, representing the initial approach to the problem. Consequently, the results involve a descriptive analysis of phenomena without the use of mathematical models to explain them. As is typical of exploratory studies, these findings serve to stimulate further research that can delve deeper into the subject matter.

### *3.2. Post-Harvest Main Activities*

Post-harvesting activities play a key role in managing the quality and safety of agricultural grains after the harvesting process. They are responsible for ensuring the integrity of the grains throughout the entire production chain [84]. Grains, being living products, require careful handling and storage, with specific considerations for cleanliness, temperature, humidity, and continuous monitoring [85]. Agricultural grains are prone to rapid deterioration and can be affected by the growth of fungi, yeasts, bacteria, and harmful mycotoxins. Failure to prevent these deterioration processes poses a risk to human consumption, including the consumption of animal products derived from grain-based feeds [86]. One of the key objectives and benefits of post-harvest activities is the loss prevention in the food production system. Various stages of the production cycle can contribute to significant qualitative (in terms of grain quality) and quantitative (in terms of volume) losses during the grain's journey within a grain storage unit (GSU). Figure 1 illustrates the primary issues related to the safety and quality of stored grains.

After the harvest, the grains are transported to a grain storage unit (GSU) using various logistical modes, such as road, waterway, or rail transport. In a GSU, there are nine critical control points (PCC) that are crucial for preventing qualitative and quantitative losses in grains. Figure 2 depicts the points. Additionally, Figure 3 highlights a representative GSU equipped by the company under study, highlighting the specific control points.

This article focuses on the post-harvest process depicted in Figures 2 and 3. The process begins with the reception of grains (PCC1), followed by the discharge into the hoppers (PCC2). The grains then undergo precleaning (PCC3) to remove coarse impurities before being transferred to buffer silos (PCC4) for intermediate warehousing. If needed, the grains route to dryers (PCC5) for a high-temperature treatment to eliminate moisture and ensure safe humidity levels for long-term storage. Next, the grains pass through cleaning machines (PCC6) to remove fine impurities that may affect their quality. Subsequently, the grains are stored in permanent storage silos (PCC7) until they are ready for commercialization. Once the sale is completed, the shipping process (PCC8) begins. Throughout the entire storage process, various crossing points (PCC9) contribute to the losses. The implementation of digital technologies can effectively address the PCCs, aiming to minimize losses in the overall process.

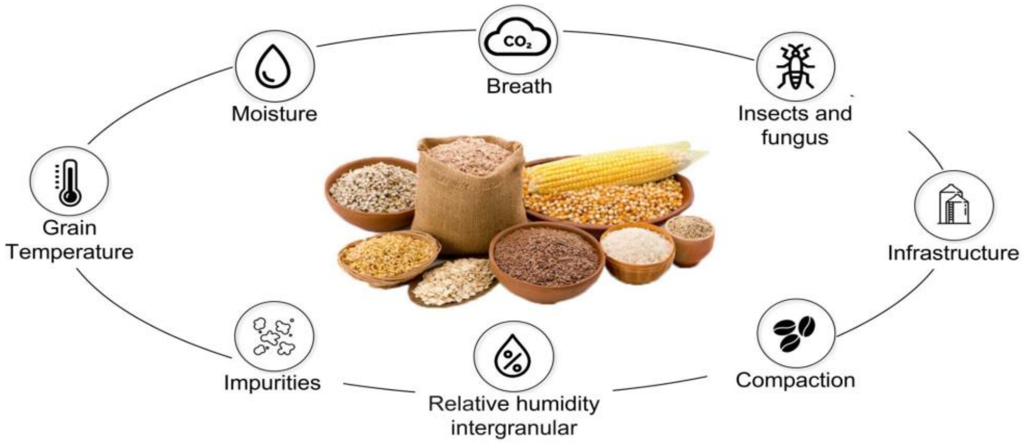


**Figure 1.** Factors that influence the safety and quality of stored grains.

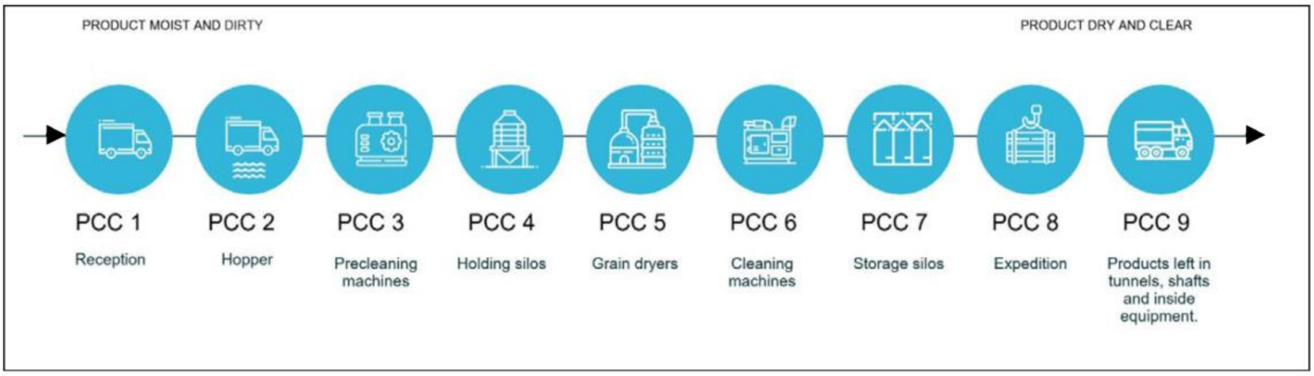


**Figure 2.** Qualitative and quantitative losses in the post-harvesting process.

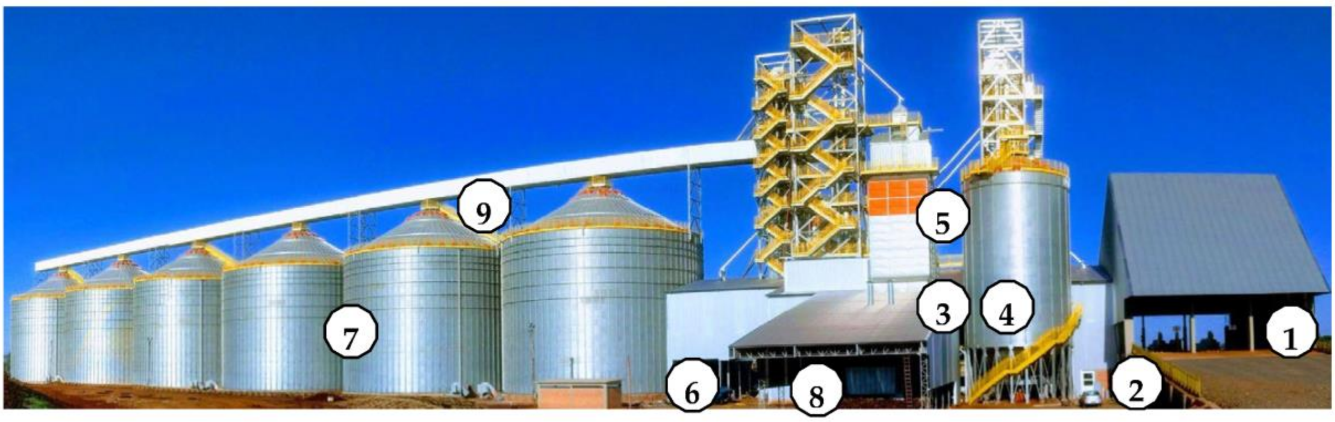


**Figure 3.** Grain Storage Unit (GSU) including reception (1), hopper (2), precleaning (3), holding silos (4), dryers (5), cleaning (6), storage silos (7), expedition (8), and internal movement (9) processes.

A thorough study delved into over 300 cases of loss reduction initiatives in post-harvesting [87]. The findings revealed a potential to decrease production losses from 2% to 28%, with an average reduction of approximately 7% and a standard deviation of around 11%. The study also uncovered that more than 80% of initiatives aimed at curbing losses focus on implementing storage technology interventions for farmers and 6% for traders.

Consequently, it seems reasonable to anticipate that digital technologies could have an average impact of around 7% on the overall volume of produce. This estimate is comparable to reports that indicate loss reductions between 5 and 8% in production volume due to the introduction of technological management elements [88].

In a grain storage unit (GSU), the drying and storage processes are pivotal. Grain dryers are equipped with various sensors and systems to ensure efficient operation, such as pressure sensors to balance mixtures in the drying air, level sensors to prevent the equipment from operating when empty, an exhaust air temperature sensor to detect early signs of fire, a frequency inverter to adjust drying speed and time, and an automatic fuel supply system to stabilize the drying temperature by regulating burning. To monitor grain quality, the system provides real-time measurements of grain moisture, drying air temperature, and grain mass. Real-time alert systems enhance safety and equipment efficiency. For storage, the recommendation is at least one temperature sensor per 150 $m^3$ of grain. The system transmits in real time through remote platform intragranular relative humidity sensors and meteorological data. The system tracks the storage evolution and grain mass temperatures, and it enables the creation of rules that link the aeration system to air renewal based on climatic conditions. Safety and quality objectives may vary based on drying, cooling, conservation methods, local climate, and the customer's strategy [84].

Dry matter loss or technical breakdown occurs during grain storage, leading to weight loss caused by chemical oxidation reactions that consume energy stored in organic compounds, such as sugars and starches. The acceptable level of dry matter loss varies, but authors suggest values between 0.1% and 0.5% [89,90]. In Brazil, field evidence establishes an official technical breakage rate of 0.3% per month of storage [91].

### *3.3. Digital Technology Products and Services for Post-Harvesting*

The company offers a range of products and services that utilize digital technologies integrated with fixed equipment throughout the entire set of processes in the GSUs. The offers include receiving, handling, precleaning, drying, post-cleaning storage and preservation, and grain shipping. Various digital field technologies assist farmers in real-time monitoring of grain temperature and humidity [92]. Additionally, virtual reality is utilized for training and inspection activities [93], while AI and CC are leveraged to predict the behavior of key variables in storage operations [94]. The literature provides a recent overview of the enabling technologies used in Agriculture 4.0 [95]. To enhance understanding, the company categorizes its offerings into three layers of products, with the first layer being closer to the physical space and the third layer closer to cyberspace.

The first layer encompasses sensors that collect data related to physiological conditions, such as temperature and humidity. It also involves gathering data on machine productivity and maintenance, utilizing sensors for flow, temperature, movement, bushing, and mechanical component alignment. This layer includes motors, standardized sequencing, and protection instrumentation, such as inductive and capacitive sensors, as well as protection relays. Finally, the layer incorporates specialized instrumentation, such as thermometry systems for monitoring temperature and humidity sensors for drying processes.

The second layer comprises control panels and supervisory systems that employ various automation architectures to manage the performance and efficiency of the entire process through preset management and process parameter control. In fully automated units, the panels can interact with each other (Machine to Machine—M2M) without human intervention, leveraging IoT technology. This capability is crucial as it supports the concept of decentralizing the automation process, enabling individual and independent control of each piece of equipment. It also allows a single control room to oversee multiple GSUs. Depending on the arrangement, the control room may or may not be located near the field. It is not uncommon for customers to control multiple GSUs from a single control room. The company exclusively sells physical equipment and add-ons from the first two layers, whether they are included in the overall engineering solution or integrated into the machinery. The equipment warranty is contingent upon the safe operating conditions ensured by the automation, control, and instrumentation systems of the first two layers.

The third layer encompasses remote digital services, typically hosted in the cloud. The company has incorporated such a service into its engineering solution since 2019. The cloud platform communicates with the second layer through gateways and internet access infrastructure. The platform features a highly adaptable interface that efficiently retrieves real-time data and information generated by the equipment's sensors. It records operational history, serving as a valuable resource for facilitating timely decision-making processes for both customers and equipment suppliers.

In terms of enabling technologies for the digital transformation of industrial processes, the company primarily relies on automation (AUT) and radio frequency identification (RFID) in the first layer. The second layer is predominantly supported by cyber–physical systems (CPS), the internet of things (IoT), and virtual reality and augmented reality (VRAR). The third layer relies mainly on big data analysis (BGA), cloud computing (CC), and simulation (SIM). Additive manufacturing (AM) plays a role in expediting the supply of spare parts and prototyping while also facilitating the development of new technologies. It is conceivable that AM will be utilized in future machinery development, particularly due to the market's requirements for modularity and scalability. Figure 4 provides an illustration of the content of the three layers.

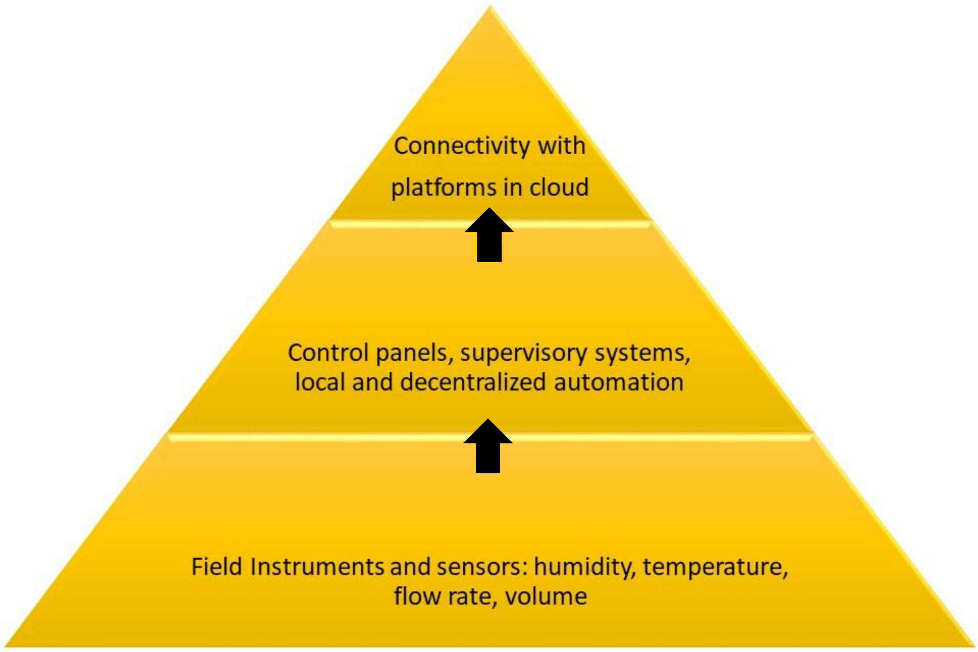


**Figure 4.** The three layers of digital products for post-harvesting that the company provides.

## 4. Types of Opportunities

The competitive priorities for providers of post-harvest solutions undergo changes as the market evolves in implementing and adopting GSU technology products. The company under study identifies five categories of opportunities for customers and stakeholders: financing, commercialization, operation and logistics, insurance, and traceability. The opportunities attract the interest of eight key players, each representing a potential customer for new products and services. The primary player is the agricultural producer, encompassing all types of opportunities. The other players include trading companies, agro-industries involved in grain purchases, financial institutions, input suppliers, insurance companies, food retailers, and end consumers. Each player establishes unique competitive priorities for every viable opportunity, aligning them with their respective value perspectives. Figure 5 provides an illustration of the different opportunity types.

Figure 6 represents a technology platform view that integrates the five types of opportunities and a sixth element, the solution provider.

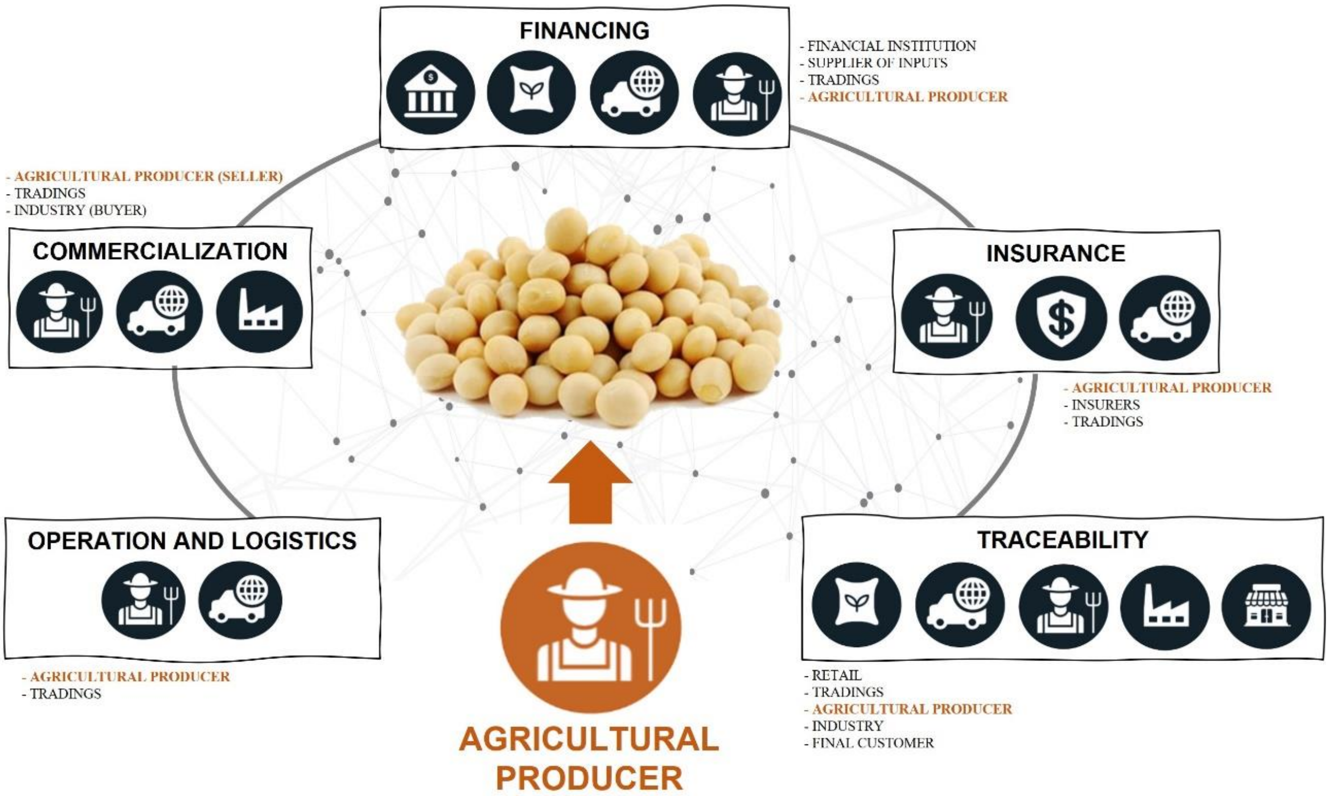


**Figure 5.** Opportunities for post-harvest solution providers.

The key component of the system is the big data machine, which harnesses data from IoT solutions integrated into the equipment. It serves as a vital link that connects to the machine-learning device, enabling the generation of essential information for the development of new products and services linked to the platform. With the assistance of a digital twin driven by artificial intelligence and other advanced technologies, the system seamlessly integrates the automation solutions within each client's equipment. The integration not only enhances the concept of autonomous equipment but also strengthens the manufacturing industry's drive toward performance enhancement. By utilizing digital technologies to extract valuable insights and knowledge from vast amounts of data, solution providers can establish continuous connectivity with customers, even beyond the delivery, installation, and commissioning of systems. Offering digital services positions solution providers as consultants, providing support and guidance to customers in their quest for enhanced efficiency and preservation of grain quality. Digital services open new and sustainable revenue streams, justifying investments in the development of innovative products. The studied company addresses the specific requirements of each opportunity type, ensuring tailored solutions for their customers.

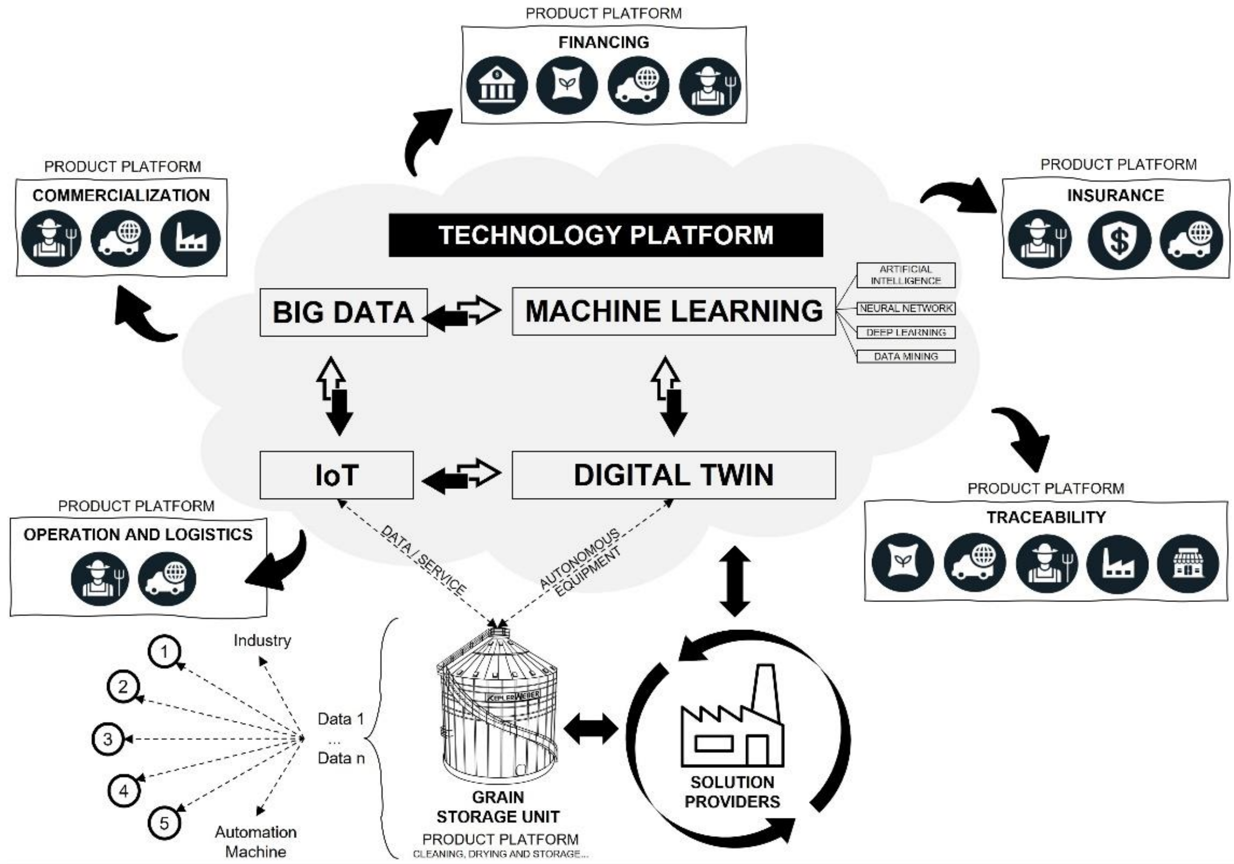


**Figure 6.** Technologic platform.

*Exploring the Opportunities*

As for financing, the main opportunity lies in digitizing the credit application process for agricultural producers, with the grain harvest serving as collateral for the loans. Financial institutions, input suppliers, and trading companies focus on minimizing default risks, while agricultural producers seek fast, affordable, and secure credit options. The platform effectively addresses the uncertainties associated with credit information and risk assessment, as well as the challenge of tracking grains covered by warranties to prevent fraud. In essence, the primary challenges faced by these stakeholders revolve around credit approval uncertainties, difficulties in monitoring warranted grain, and the risk of fraud. Additionally, agricultural producers face the additional challenge of convincing financial institutions to have faith in the effectiveness of their production. Historical data that showcase the producer's performance and punctuality become crucial in securing lower interest rates, gaining preferential access to financial resources, and becoming eligible for more stringent yet government-subsidized financing options.

As for commercialization, trading companies, agro-industries, and producers share a common need for improved reliability in purchase and sale operations, along with agility and security in transactions. Trading companies and buyers prioritize reducing transaction costs and mitigating uncertainties associated with receiving goods, which involves accessing information about input and grain quality, market price quotations, minimizing storage expenses, expanding storage capacity, and establishing connections with new grain producers. Platforms effectively address these limitations by providing the necessary tools and information. On the other hand, producers aim to secure the most favorable commercial conditions in terms of price, receipt timeframe, and contract closure speed. They require access to information that reveals the correlation between grain price and quality, streamlined transaction processes, and connections to new grain buyers. Platforms effectively address these limitations by providing the necessary resources and connections to facilitate efficient and favorable trade for producers. In summary, platforms play a vital role in meeting the needs of trading companies, agro-industries, and producers by enhancing reliability, reducing costs, mitigating uncertainties, and facilitating efficient and secure transactions.

As for operations and logistics, producers and trading companies have specific requirements. Producers are looking to expand their warehousing capacity and maintain their current equipment. They also seek solutions for maintaining grain quality through advanced quality control methods and monitoring services that improve efficiency and reduce waste along the entire grain supply chain. By integrating e-commerce solutions with IoT data from customer-installed equipment, proactive measures can anticipate preventive and predictive maintenance needs, optimizing services and parts. Additionally, the technology platform-backed e-commerce system can identify new business opportunities, such as expanding capacities in GSUs and offering equipment and technology acquisitions to both existing and potential customers. Producers face challenges, including the high costs associated with acquiring and maintaining silos, a lack of tools for grain quality control, heavy reliance on manual labor, time-consuming and costly transshipment, and transportation stages that often result in contract non-compliance, fines, and deterioration of grain quality during prolonged storage. On the other hand, trading companies encounter difficulties due to the absence of quality control tools for stored and in-transit grain, excessive reliance on manual labor in transportation, and the lack of grain monitoring during transshipment and transportation, leading to waste and losses. Such challenges ultimately have an impact on the agro-industry, food retailers, and consumers. To overcome limitations, the use of automated, integrated strategic platforms can prove beneficial. Such platforms offer comprehensive solutions that address the specific needs of producers and trading companies, streamlining operations, enhancing efficiency, and ensuring the maintenance of grain quality throughout the entire supply chain.

As for insurance, one of the main challenges is to digitize the insurance contracting process and leverage technology for intelligent risk analysis and remote monitoring of risks associated with harvest, storage, and transportation. The key stakeholders are insurance companies, trading companies, and producers. For insurance companies, it is crucial to mitigate risks by conducting more efficient and cost-effective inspections of agricultural properties to reduce fraud and cargo theft. Insurers often face difficulties due to the high-risk nature of the agricultural activity, which leads to high inspection costs, low inspection efficiency, and a prevalence of fraud and cargo theft incidents. Trading companies, on the other hand, face the challenge of enhancing security against fraud, theft, and returns. They strive to protect their interests and minimize potential financial losses resulting from these risks. Producers consider insurance as essential for mitigating uncertainties and ensuring a financial return on their crop investments. However, high insurance policy prices pose a significant difficulty for them. An integrated platform provides producers with the ability to compare prices and benefits offered by different insurers. Additionally, by presenting reliable information on historical productivity, producers can diminish the insurer's risk perception, resulting in lower-priced insurance policies for them. Overall, digitalization and the integration of platforms in the insurance sector address challenges by streamlining processes, enhancing risk analysis capabilities, reducing fraud incidents, and providing greater transparency and cost efficiency for all parties involved. By embracing technology and digital solutions, insurance companies, trading companies, and producers can benefit from improved efficiency and effectiveness in managing insurance contracts and mitigating risks associated with agricultural activities.

As for traceability, the primary challenge lies in establishing a digital platform capable of integrating information across the entire supply chain, which includes cleaning, drying, and storage processes. By incorporating comprehensive and integrated information, it becomes possible to establish standardized commercialization norms and certify the product's origin and quality for the market. The key stakeholders are producers, trading companies, buyers, and retailers. For producers, trading companies, and buyers, the certification of grain origin and journey is of utmost importance to ensure product quality. This includes aspects such as verifying the appropriate use of pesticides in harvest management. Producers face challenges related to adopting product quality standards and pressures from various stakeholders to identify and reduce pesticide usage while embracing environmentally sustainable practices. Trading companies and buyers struggle with limited monitoring capabilities throughout the transportation, storage, and processing of grains due to a multitude of suppliers and product mixes along the supply chain. Additionally, they face increasing pressure to adopt sustainable practices and ensure environmental safety. For retailers and consumers, the supply of nutritious, healthy, and environmentally safe food is paramount. It is equally essential to have monitoring data and assurance of food safety for the end consumers. Overcoming these challenges relies on reliable tracking systems and accurate information regarding the origin, journey, and quality of the food products. Addressing these challenges requires the development and implementation of robust traceability systems that track and record essential data points throughout the supply chain. By leveraging digital platforms and integrating information, stakeholders can ensure transparency, reliability, and compliance with quality and safety standards. This enables consumers to make informed choices about the food while promoting sustainable practices and fostering trust throughout the supply chain.

Table 1 depicts the main implications of the study and the opportunities that digital transformation conveys for players interested in the solutions provided by the company.

**Table 1.** Synthesis of the implication of the study.

| | Opportunities | | | | |
|---|---|---|---|---|---|
| **Players** | **Financing** | **Commercialization** | **Operation and Logistics** | **Traceability** | **Assurance** |
| Producers | Credit cheap and fast | Increased reliability | Increased grain quality | Origin certified | Reduced cost |
| Trading companies | Reduced default risk | Increased reliability | Increased grain quality | Origin certified | Reduced risk |
| Agro-industry | | Increased reliability | Increased grain quality | Origin certified | |
| Financial institutions | Reduced default risk | | | | |
| Suppliers | Reduced default risk | | | | |
| Insurance companies | | | | Information | Reduced risks |
| Food retailers | | | Increased food quality | Safer food | |
| Consumers | | | Increased food quality | Safer food | |

## 5. Final Remarks

Digital transformation is the process an organization applies to integrate digital technologies into its business, fundamentally changing how it delivers value to customers. Digital transformation can, at the same time, increase productivity, improve the customer experience, and reduce operating costs. In post-harvest activities, particularly in GSUs, digital technologies have given equipment autonomy to communicate with other machinery and collect data required by automatic platforms of strategic management.

The purpose of this article was to identify opportunities that digital transformation in post-harvest activities offers to an engineering solution provider. The research method was a simple case study. The object of study was a company based in southern Brazil that provides integrated engineering digital solutions, including products and services, to grain producers. The primary findings included the differentiation of the company's products into three technological layers, the identification of five important opportunity kinds and eight players, and the potential contributions of each technology to the top players in each opportunity type. The types of opportunities are financing, commercialization, operations and logistics, traceability, and insurance. The players are grain producers, trading companies, the agro-industry that purchases grains, financial institutions, input suppliers, insurance companies, food retailers, and final consumers. The digital transformation presents a host of opportunities, many of which are already implemented, across various aspects of the production chain for post-harvest services. The implications include the following:

(i) Digitalization of credit taking: The adoption of digital processes and platforms for credit applications and approvals, streamlining and expediting the financing process for producers;
(ii) Digitalization of purchase operations: Implementing digital solutions to facilitate purchase transactions, improving efficiency, and reducing costs for trading companies and agro-industries;
(iii) Digitalization of sale operations: Utilizing digital platforms to enhance sales processes, enabling faster and more secure transactions for both producers and trading companies;
(iv) Digitalization of grain quality control: Leveraging digital technologies to monitor and control grain quality throughout the supply chain, ensuring higher standards and reducing quality-related risks for all stakeholders;
(v) Digitalization of food safety control: Implementing digital systems and technologies to enhance food safety protocols, enabling better traceability and ensuring the delivery of safe and high-quality food products to consumers;
(vi) Digitalization of grain movement information: Utilizing digital platforms to track and monitor grain movement, providing real-time information on storage, transportation, and logistics, resulting in increased transparency and efficiency in the supply chain;
(vii) Digitalization of insurance contracting processes: Adopting digital solutions for insurance procedures, simplifying and streamlining the contracting process, reducing costs, and improving risk assessment and management for insurers, producers, and trading companies.

Integrating field equipment with management platforms is a crucial aspect of this digital transformation, enabling data collection, analysis, and decision making. By embracing digital opportunities, the actors in the post-harvest services production chain can unlock significant value, improving efficiency, reducing risks, and enhancing overall performance. According to the Brazilian Company of Food Supply (CONAB), Brazil's grain production for the 2022/23 harvest may surpass 313 million tons [96]. The company highlights that each percentage point of error, for instance, in humidity control, may lead to a loss exceeding 3 million tons, which emphasizes the economic feasibility of employing technology to preserve the physiological and quantitative integrity of grains. By utilizing monitoring and automation systems capable of autonomous decision making with minimal human intervention, losses diminish while augmenting the global grain supply.

This study makes room for additional research. One possibility is constructing a framework or roadmap that guides a company's digital transformation and provides post-harvest activity solutions. Another option is to survey the company's customers (there are more than a thousand rural producers around the globe already served by the studied company) to understand the digitalization stage the industry is in and, mainly, what competitive priorities rural producers aim to meet with the digitization. Finally, multiple case studies should describe the peculiarities and difficulties of customers with digitalized products and processes and the digital transformation of the implemented solutions.

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