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Digital Twin in the agri-food supply chain: a literature review

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Abstract. The present manuscript aims at presenting some preliminary results from a literature review carried out on the existing documents dealing with Digital Twin models within the context of agri-food supply chain, in order to assess the state-of-art of such new technology for this promising field. The analysis considers both descriptive metrics (i.e., year of publication, research type, geographical origin and keywords analysis) and qualitative aspects (i.e., subdivision according to the supply chain phase involved and data-driven *versus* physic-based modelling of the Digital Twin solutions presented in the documents).

Keywords: Digital Twin, Industry4.0, Agri-Food Supply Chain, Literature Review; Food Industry.

1 Introduction

As one of the keywords of the Industry4.0 paradigm is “digitalization”, recent technologies enabling this digitalization are not missed, of course.

One of these, is the Digital Twin (DT). A DT is basically defined as *a virtual representation of a physical system (and its associated environment and processes) that is updated through the exchange of information between the physical and virtual system* [1], typically involved for real-time prediction, monitoring, control and optimization of the asset for the improved decision-making throughout the life cycle of the asset and beyond [2]. In other words, a DT reflects the physical status of a system in a virtual space [3], thus allowing to describe the process, the product or the service through mathematical models in order to carry out analyses based on data collected from sensors, from experts or from other machines integrated with historical data [4]. According to that, they allow to reply to the question “what happens if...?” without carrying out physical experiments, but just through analyses and simulations.

DTs are implemented in different contexts; for instance, within the field of medicine e.g. for simulating cardiac electrophysiology [5] or for enabling the vision of precision cardiology by building a DT of a patient [6] or even for defining personalized therapies for precision oncology [7]. Within the field of education, for instance for creating a holographic classroom in order to promote the reform and reconstruction of learning spaces and learning modes [8] or for the development of the DT of a smart campus for

monitoring the comfort [9]. Again, several applications were developed in the industrial context; in this light, as in this field the DT technology is more spread, the authors recall interesting literature reviews on different specific areas in which the DT turned out to be implementable and relevant, such as that of safety in manufacturing [10], additive manufacturing [11] or maintenance [12]. It follows that DT solutions can be involved for different purposes.

Remaining in the industrial sphere, the aim of this paper is to investigate the state-of-art of literature related to a promising field for DT solutions, namely that of agri-food supply chains (AFSC in the following). Dealing with products, quite often temperature sensitive, having specific constraints (e.g., the shelf-life) and being constituted by different actors having different roles in different supply chains [13], the AFSC has great challenges to face and can offer interesting research insights related to digitalization; however, as it will be highlighted in this manuscript, this technology is still at an embryonic stage in this field as also demonstrated by the limited number of documents found. Indeed, to this end, a literature review was carried out on 14 scientific papers, analyzing both descriptive and qualitative aspects. Despite there are other literature reviews dealing with DT applications such as those already mentioned few lines above, none of them is focused on a specific industrial sector; hence the novelty of the paper, since there are no evidences of previous studies referring to the AFSC.

The remainder of the paper is as follows: section 2 describes the methodology, followed by section 3 in which descriptive parameters are illustrated and section 4 which deals with the contents analysis. Finally, brief conclusions are provided in section 5.

2 Methodology

In August 2020 different queries were launched on respectively Scopus (www.scopus.com), Web of Sciences (www.webofknowledge.com) and Google Scholar (scholar.google.com) databases, including keywords dealing with the topic in question, i.e. “digital twin” AND “food”, “digital twin” AND “food industry”, “digital twin” AND “cold chain”; note that for exporting results from the Google Scholar, the software Publish or Perish (<https://harzing.com/resources/publish-or-perish>) was also involved, returning more than 1,000 documents. No constraints on type, year of publication or language were set.

After a careful check on title and abstract, the sample turned out to be constituted of 14 papers; this result is in line with Scopus and Web of Science outcomes (19 papers for the first and 9 for the second), since Publish or Perish allows to access documents in which the selected keywords appear everywhere in the full text (even in the reference lists, for instance), and the number of off topic papers was extremely high. Specifically, the documents included are 6 journal papers and 8 conference papers.

At first, descriptive parameters were investigated, namely year of publication, research type, geographical origin and keywords analysis. Then, the contents analysis follows: papers were firstly divided according to the phase of the supply chain they deal with, and then according to the modelling used in the development of the DT (i.e.

physic-based or data-driven). In the following, these aspects will be clearly deepened and better defined.

3 Descriptive Analysis

3.1 Temporal evolution

The first aspect investigated is the year of publication of the 14 papers constituting the sample. The first document appears in 2017, highlighting the novelty of the topic, and it is the only one published in that year. Two papers were instead written the subsequent year, i.e. 2018, eight in 2019, the most productive year, and finally three in 2020. Note that for this last year four months are missed due to the period in which this study was carried out, and it is reasonable to expect that more papers could have been published.

Hence, the trend can be defined as timidly positive.

3.2 Type of research

The second descriptive parameter considered is the type of research presented in the 14 papers. This classification is particularly useful for understanding the state-of-art of projects and applications of DT solutions.

Specifically, four types of research were recognized:

- *Review*: documents dealing with literature analysis related on a specific aspect;
- *Technical papers*: papers in which the development and implementation of a DT solution within the food context is treated, however without practical outcomes and implementations (in other words, only dealing with theoretical applications);
- *Partial Experiments*: documents dealing with the preliminary presentation of results or on a specific phase of the development of a DT;
- *Application Papers*: full practical applications and implementation of a DT solution.

Within the sample, two papers were identified as being literature reviews, five technical papers, three partial experiments and finally four full application papers.

It follows that most of the papers do not deal with a full presentation of a DT solution; indeed, most of the documents present partial applications or are limited to the design phase of how the solution could be implemented or illustrated the benefits which could be achieved.

These outcomes gain further value if we consider the type of research linked to the year of publication, shown in table 1.

Table 1. Type of research related to the year of publication.

Publication Year	Reviews	Technical Papers	Partial Experiments	Application Papers
2017	-	1	-	-
2018	-	2	-	-

2019	1	1	3	3
2020	1	1	-	1
Total	2	5	3	4

As it is possible to note, 2019 can be considered a year of considerable development of the technology, both from the point of view of application papers and from the partial experiments side, suggesting that many projects are currently in progress; 2018, instead, is the year presenting most of the technical papers (two). According to that, the subdivision turned out to be consistent with the time trend and the evolution of the topic: the first documents do not enter specifically in full applications and are preliminary presentations, but are progressively oriented towards the implementation of solutions.

3.3 Geographical Distribution

The geographical origin of the documents, aiming at assessing most productive countries or regions, was made according to the affiliation of the first author of the document. Due to the small number of papers constituting the sample, results are presented according to the continents rather than on the specific countries. Specifically, most of the contributions come from Europe (seven documents), followed by America (four), Asia (two) and Africa (one). No papers from Oceania. This could be actually due to the fact that in Europe and America we find the most industrialized countries, having also an intensive food production.

By further deepening, it is worth mentioning the United States with three publications, and Switzerland again with three documents, two of which proposed by the same team of authors and dealing with the mango cold chain, recalled in the content analysis.

3.4 Keywords Analysis

Quite common in studies of this kind among the descriptive parameters, is the keywords analysis [14]. Due to the limited number of papers, only the absolute frequency is considered. A total of 64 keywords was identified, and they were divided into three macro-categories according to the topic they represent: “digitalization”, “AFSC” and, finally, “other” in case of particular keywords not belonging to the two previous classes and accordingly off topic compared to the topic of this review.

In the first class we find 27 keywords; due to constraints set on the length of the paper, we only refer to those having frequency equal or greater than two, namely, as expected, digital twin (with a frequency of 9), artificial intelligence (2), internet of things (2) and robotics (2). The relation with artificial intelligence is immediate; indeed, DTs are also defined as artificial intelligent virtual replicas of physical systems [15]. Internet of things as well is quite obvious, since this technology is one of the enabling technologies allowing the development and implementation of DT solutions, while robotics is one of the fields of potential applications of DT.

In the second class, related to the AFSC, all the 13 keywords found have frequency equal to 1; the only one in line with the topic of this study are food equipment, food security, cold chain and food. The remaining (e.g., mangos or livestock disease) are quite far from our specific argument and more niche and specific.

The last class, less important, includes keywords considered off-topic, such as sustainability, pharmaceutical, pandemic, or safety, referring to the content of the papers.

4 Contents Analysis

The most interesting outcomes originate from the contents analysis. For this purpose, the authors decided to divide papers according to the phase of supply chain to which the DT solution is intended to be implemented, or at least studied, and according to the modelling of the DT itself, namely if it is data-driven or physic-based.

As far as the first subdivision, it is worth recalling that in an AFSC, and more in general in a supply chain, three phases are identifiable: the supply stage, the production stage and finally the distribution. In this context, however, by “supply” we mean a phase in which the product is treated as raw material, including activities such as cultivation or farming; the remaining two stages deal with industrial transformation and subsequent distribution. For the second classification, instead, by “data-driven modeling” we mean a DT whose analysis is made on historical and collected data elaborated through Machine Learning tools, while by “physic-based” it is meant a model based on a physics approach, namely relying on the observation of a real phenomenon and then on the formulation of mathematical equations which can describe it and provide for resolutions on the bases of different behaviors. In the below subsections results are illustrated.

4.1 Classification according to the supply chain phase

Overall, we identified 6 papers dealing with the first supply chain phase, 5 with the second and, finally, 3 with the third. It immediately emerges that the most investigated area is that related to the raw materials production, while less attention has been paid towards the distribution stage, despite its relevance above all when dealing with cold chains. This is in line with the spread of the topics of Smart Farming and Precision Farming, as a result of the paradigm of Agriculture 4.0, including DT solutions [16].

For the sake of brevity not all the studies are mentioned, only the most interesting.

Dealing with the first phase, we found the work by [17], who proposed an innovative system for improving irrigation; by [18] who presented a model to implement DTs in sustainable agriculture, specifically through the joint creation of physical and digital layers of IoT-enabled structures for vertical farming; by [19], who discuss the possibility of creating a DT of the planet Earth to determine and quantify the environmental impact of innovations in agriculture; by [20], who developed a DT for replicating and simulating a livestock farming to face livestock disorders; finally, by [21] who studied the implementation of DT for aquaponics in the fisheries sector, with control and monitoring purposes. For a complete overview, finally, we mention the literature review by [22], whose focus is on general DT applications in supply chains, but has a section dedicated to the implementation in food contexts and precision agriculture.

Related to the transformation phase, i.e. the second one, we found five studies, whose attention is shifted to the industrial production. In particular, relating to this phase we found the oldest paper, by [23], in which the DT is implemented for monitoring the variation of CO₂, temperature, humidity and PH in the three steps of the malting

process; we also found an application to a whole water bottling line for optimizing production and avoiding bottlenecks [24]; finally, a DT of a pasteurizer was developed for operators' risk prevention [25].

The less debated aspect, as already stressed, is related to the distribution stage; in this case only three studies have dealt with this issue, and among these the already mentioned Swiss papers, [26] and [27], in which a DT of a mango is proposed, in order to study its cooling level and determine its impact on the quality of the fruit during the transportation and storing stages; in the first paper the project and the general architecture are presented (partial experiment), while in the second one, various simulations of the system behavior were carried out (application paper).

4.2 Data-driven vs. Physic-based modeling

The second and last qualitative aspect under investigation is the nature of the modelling for developing the DT solutions, with the meaning detailed at the beginning of the present section. Overall, we found 7 data-driven papers and 4 physics-based ones; clearly for the 2 reviews this aspect was not determined, as well as a for a single paper in which different solutions for farming were proposed. Table 2 below summarizes results from this classification, including the linkage with the supply chain phase. It is interesting to note that for the transformation step, exception made for one document, all the DT models are data-driven; indeed, for industrial processes it is easier to collect data, both in terms of input and output.

Table 2. Classification of the modelling linked to the supply chain phase.

PHASE:	Supply	Transformation	Distribution
MODELLING:			
Physics-based	2	-	2
Data-driven	2	4	1
Not Available	2	1	-

5 Conclusions

The present paper aimed at presenting some key results from a literature review carried out on 14 papers whose focus was the development or the implementation of Digital Twin solutions in the field of agri-food supply chains, a promising context for solutions of this kind, above all, as emerged, in the agriculture field.

For sure, we are aware of the limited number of papers under investigation; however, this actually can be seen as a symptom of the fact that specific literature and applications of this kind are still lacking and are at an embryonic stage.

However, it can be conjectured that this technology can bring multiple benefits. First of all, it allows monitoring and identifying process anomalies in a timely manner, but above all it makes it possible to make predictions of these anomalies and possible behaviors either through Machine Learning algorithms or by solving complex physical

equations. Moreover, an automated management of production systems can be allowed, as well as resource usage optimization, fundamental aspects in the light of the challenges that our planet is currently facing.

Being a recent and innovative technology within the AFSC, several insights can be provided. Specifically, further analyses and studies related to the food industrial production are highly recommended, thus enabling savings and higher efficiency of processes. Moreover, for sure it is in plan to extend the literature review and the sample size by the end of the year, in order to include more recent studies, hopefully numerous.

Finally, note that for those interested readers the full list of reviewed papers can be made available, as well as the Excel spreadsheets used for the analyses.

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