The AI Digital Revolution in Innovation: A Conceptual Framework of Artificial Intelligence Technologies for the Management of Innovation

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Artificial Intelligence (AI) is an emerging technological field with immense transformative potential. Within this context, we discuss the diverse ways AI is transforming innovation. We introduce a conceptual framework in which we argue AI plays the following two roles: originator and facilitator of innovation. Additionally, we discuss different applications and implications for innovation theory and practice using a reflection on the traditional innovation process and the front end of innovation perspective. For this, we use the perspectives of AI as technology push, AI as market pull, AI to advance steps in the innovation funnel as well as AI as a contributor to new product development. Finally, we discuss future directions for research in these fields.

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SECTION I.
Introduction and Background

Artificial Intelligence (AI) is set to become the key enabling technology of the 21st century. Hence, it is unsurprising that investors worldwide have set their sights on AI companies, particularly AI-related startups (see Fig. 1). AI companies attracted over $26 billion in investments in 2019 alone [1]. It is also unsurprising that in the past decade, both private and governmental programs have exponentially increased their investments in this technology. AI's generative and mutable characteristics have enabled the rapid identification of potential applications by entrepreneurs and innovators alike. While the hype around the technology is not new [2], [3], digitization is increasingly driving AI's potential into a new dimension within the broader phenomenon of digital transformation [4].

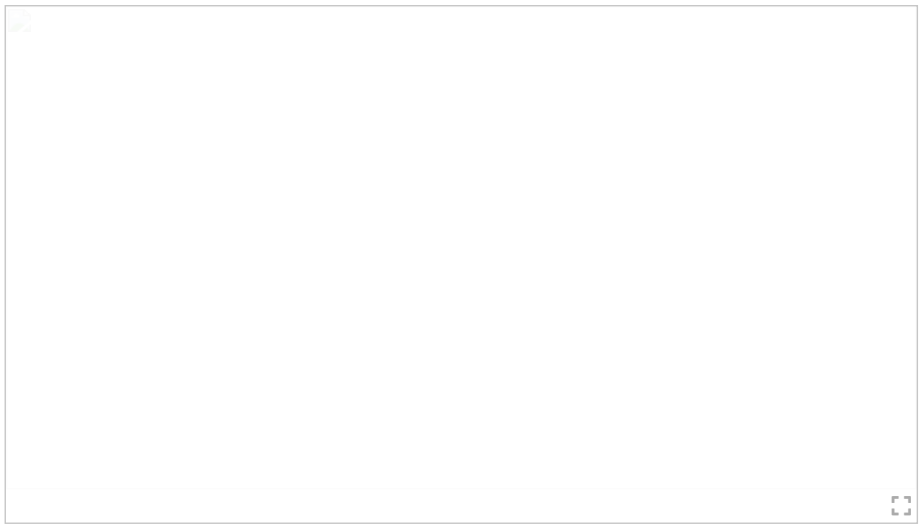

Fig. 1.
Deals and funding of AI-related startups. (Source: [1]).

While AI's development as a technology is exciting, an open question remains: How will AI transform innovation at different levels? AI has the potential to change how innovators make decisions [5], how ideas and new products and services are generated and designed [6], [7], how data from users are leveraged for new business models [8], and among other areas. We propose to organize these potential AI areas in relation to the innovation process [9], identifying how potential applications of AI technology resonate with the specific challenges of innovators.

To this end, we introduce a two-part conceptual framework: The first part views AI as a technology that can fulfill different roles within a company, and the second looks at AI and its use along the company's innovation processes. In the following sections, we introduce both parts and discuss them using examples from existing field applications, as well as describe potential areas for future research and limitations to this framework.

SECTION II.
AI as a Technology in the Management Context

AI is included in the larger set of digital technologies (including, e.g., blockchain or IoT). It shares common characteristics related to the nature of technology, but it also has differential aspects that help explaining the continued attention the technology has received.

Following the conceptualization by Yoo *et al.* [10], digital technologies share the following three essential commonalities that separate them from other technologies: first, they are reprogrammable, second, they create, share, and capture data as a homogeneous source, and finally, they reinforce each other by self-referencing.

First, in contrast to other technologies, the digital nature allows to reorganize the tasks and repurpose the technology for another function than originally designed. This is a unique feature as it breaks from the physical limitation of other technologies and opens the door to recode and reinterpret what functions should a digital technology perform. This means that new uses for the technology can emerge even after it has been deployed to fulfil a specific function in a particular application context.

Second, the interoperability of digital technologies builds upon a common type of asset that is data. Although there are multiple languages and encoding options for different types of data, there exists the possibility to decode and share data across digital technologies. This opens the door to connecting them and building complementarity functions that are often not possible with physical technologies. It is not only that “data is the new oil” but also that “data is the generative backbone” that connects and enables other digital technologies to expand the possible functions and applications.

Third, digital technologies reinforce and reference each other. The proliferation of digital devices and the exponential growth of new digital products and services strengthens and reinforces the value of each digital technology. Following the logics of economies of scale, there are both: growing benefits as the number of devices or products increases, as well as faster learning times that shorten the development of new applications. At the same time, this reduces entry barriers for new entrants that can use existing and new digital technologies to contribute (and at the same time further reinforce) the interconnected and interoperable digital innovation systems.

A. Differential Aspects of AI as a Digital Technology

AI incorporates, at least, the following two differential characteristics: first, opaqueness and second, self-learning. Compared to other digital technologies, AI has followed a slower historical development. While the concept of AI as a technology or even a science has been in discussion for decades [11], its actual development has relied on ongoing statistical developments, and more recently become fully embedded with computer (and computational) science advances. As a result, this has generated two differential new characteristics, its inner principles and working mechanisms are not necessarily visible, and it has gained self-learning capabilities.

The increasing complexity of the mathematic and statistic tools being used, and the interconnections between multiple methods and tools, gives to AI the possibility of being “opaque” to the user of the technology. This means that the user of the technology might not always be able to get full access (or see) how the algorithm operates, neither to modify it without losing part of the functions. This also means that in some cases it operates like a black box, where there is a data input and a data output, but where there might be decisions automatically encoded in the process that are not fully observable by the user of the technology.

The opaqueness feature can contribute to the diffusion of the technology, as it reduces the risk of alterations of the core functioning mechanisms, supporting standardization. But it can also impact on further usage and adoption if the developer of the algorithms has overlooked (internationally or not) some aspects or considerations. This is something we will discuss again later as we explain the ethical considerations of AI applications and how we should consider the differential aspects of the technology as more and more innovative applications emerge.

Regarding the self-learning capability, and unlike conventional software algorithms, which are based on deterministic logic to be employed in static environments [12], AI applications have inherent cognitive and intelligent capabilities and respond to their environment [5], [13].

AI applications are based on extensive computing resources that can collect, process, and analyze large amounts of data from various sources [14]. A branch of computer science, AI manifests as multiple technological subbranches, such as machine learning [15], deep learning [16], natural language processing [17], and computer vision [18] (see Fig. 2). AI applications generally rely on statistical models, which are applied to historical data. From these models, an AI algorithm learns a decision model for a specific task, which is then applied to new input data. One facet of AI algorithms is that they improve their decision precision with continuous exposure to more and new data [15], [19]. In this way, AI applications take over cognitive tasks, such as prediction [14], classification [18], and clustering [17], and have the potential of being self-innovating [19].

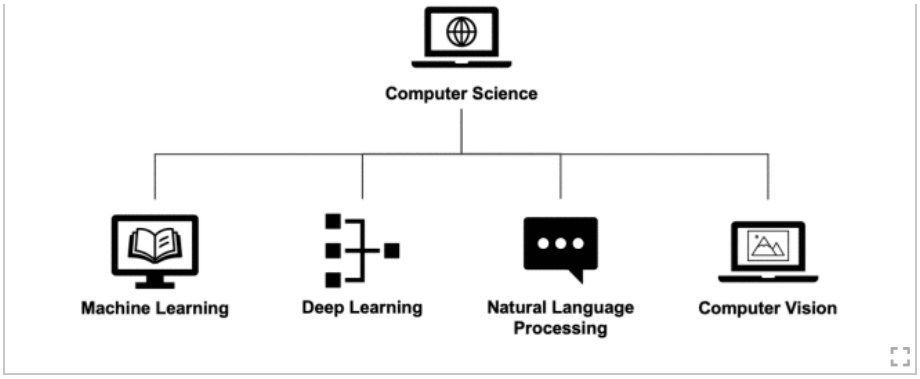

Fig. 2.
AI branches of computer science. (Source: authors' elaboration).

In the business context AI is defined as enabling machines to be responsive in an environment and to identify correlations, features, and similarities in large amounts of data. This development has been enabled in the past years given cost-reductions in digital technologies to collect, store, process, and analyze data and steady improvements in algorithm performance [20]. AI has been characterized as using its cognitive capabilities to autonomously carry out tasks previously done by humans [21] or to supplement and support human workers in a wide range of areas [22], [23]. The potential of the technological field is manifold, making it applicable across industries [20] and business functions [22], [24].

AI is already applied to enhance and automate existing and new products, services [13], and processes [16]; reshape customer interactions [25]; identify new innovation fields by expanding search spaces [17]; and identify early but potentially significant signals in the corporation's environment [14]. The wide range of applications, as well as the complementarity of AI applications and human work, are leading to new forms of human-only, human–machine, and machine-only decision-making—ultimately changing how organizations learn and evolve [15], [22].

In innovation, authors emphasize AI's potential on the search and recombination function [13]. Given its potential to collect, process, analyze, and synthesize vast amounts of data from various sources, AI enables companies to widen their search space [14]. This new information enables companies to produce more exploratory ideas [26]. Furthermore, given its characteristic as a general-purpose technology, AI and related fields like robotics enable the creation of entirely new solutions, similar to previous general-purpose technologies like microchips and the internet [18].

B. Unpacking the Impact of AI as Originator or Facilitator of Innovation

Within this context, we argue that AI as a technology ultimately leads to the following two viewpoints: AI as an "originator" and AI as a "facilitator." The enabling functions of AI technologies matter in different ways, especially in terms of how we explore these technologies' impact in an innovation context. In this article, we call these enabling functions the originator function and the facilitator function (see Fig. 3).

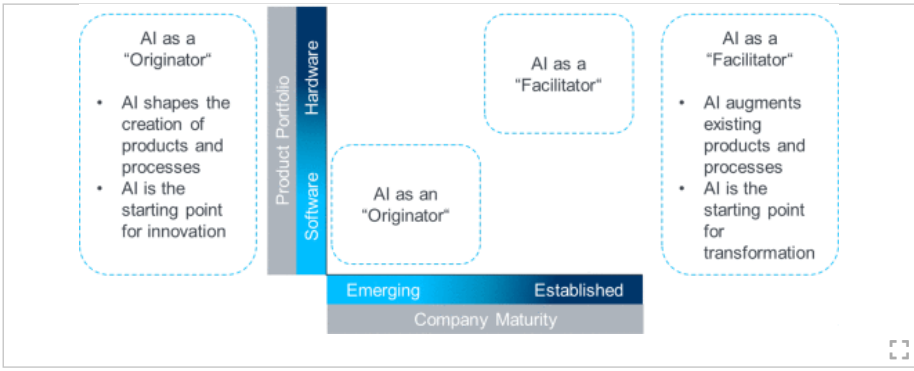

Fig. 3.
AI as originator and facilitator. (Source: authors' elaboration).

The originator function builds on the notion of AI as a method of inventing, especially in the context of classification and prediction tasks [18]. It powers an individual's capacity to explore a massive array of possible solutions and provides certainty in unknown contexts, leading to the mitigation of perceived uncertainty and reducing the perceived complexity the decision-maker faces [5]. This

function combines AI's generative and creative potential, based on advances in machine learning and deep learning [18], to explore its intelligent-sensing capabilities. As a result, this function is particularly appropriate for the early stages of the entrepreneurial process, in which the entrepreneur struggles to find possible solutions to identify problems or is lost in the search for the product-market fit.

By contrast, the facilitator function builds on AI's enabling capacity to integrate and combine data in new ways. Much of this function relies on the advances in machine learning we have seen in recent years [27]. The facilitator function relies on the ability to use AI in order to learn about opportunities to improve the processes that drive innovation [15] in established corporate structures, as in the well-known stage-gate process with modern agile hybrid adaptations [28]. Instead of creating a new organization or business model, the facilitator function helps, for example, redesigning how we identify and interact with lead users [6] or learn what changes to introduce into services to make them more successful [7]. This function thrives with data, the more data that can be accessed, the more valuable will the application of AI be. The rapid growth and expansion of tech giants have provided sustained evidence on how data becomes the fuel driving the facilitator function [8].

While most attention will remain on how much funding AI startups are raising,[1] we aim to use this dual framework to encourage future research that looks deeper. There are multiple opportunities to find approaches to understand how innovators are leveraging AI's power to transform how new ventures are created and how innovative organizations are managed. To this end, we outline the roles of AI technologies in the context of the innovation process.

SECTION III.
AI's Role as an Input Factor in the Innovation Process

Years before the rise of AI, information technologies led to notable changes in companies' innovation process. Particularly noteworthy are the invention of the personal computer and the rise of the internet as a communication platform. Especially in the context of large corporations, business convergence is driven by a process of technological convergence [29]. Such a convergence is also to be expected with AI.

The initial idea of innovation structures has remained stable in recent decades. Under this concept, related innovation processes vary for each company and depend on many factors. Scholars established a basic understanding of innovation structures that links thinking in a funnel [30] to stages, including stop and go decisions [28]. Another established framework is the technology push versus market pull perspective [31], which is also used here to introduce our conceptual framework. This perspective has a common starting point, an opportunity, that is generally based on technology push or market pull impulses. The opportunities go through a funnel-shaped structured innovation process with different stages and gates, and the ones that make it through reach the back end of innovation. The back end—where ideas are turned into practice—usually consists of hardware and software development, including stages such as prototyping and manufacturing development. For AI-induced technologies, this process is not so different from the process in other technological areas. However, this framework is ideal to uncover AI technologies' potential to revolutionize innovation management as we know it. (See Fig. 4 for the innovation funnel; numbers 1–5 refer to example areas in which AI demonstrates potential for innovation management and new product development, as discussed in the following sections.)

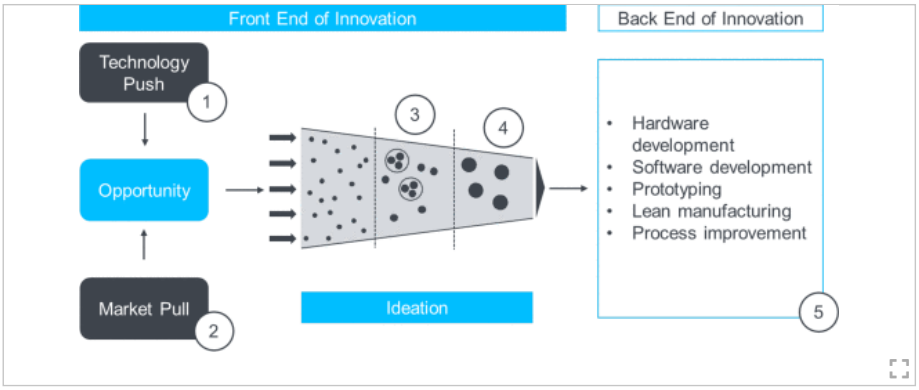

Fig. 4.
Combined view of the innovation process, with innovation funnel in the front end of innovation. (Source: authors' elaboration).

A. AI's Technology Push Perspective

The first area, technological push, offers an interesting starting point for applying AI technologies. Early signs of technological change can be spotted by analyzing large amounts of information, such as patent data or scientific publications (which are sometimes publicly available). With AI, relevant documents can be retrieved and analyzed in seconds to identify topics and determine whether these topics are emerging or declining (e.g., based on the number of publications over time). With the help of human experts, topics can be interpreted and prioritized. Kölbl *et al.* [17] introduce a case study involving robot surgery, in which new application fields were missing. The team created a search query with relevant terms for their subject, collecting 4010 patents from the European Patent Office and analyzing them using Latent Dirichlet allocation and linear regression. As a result, they found areas for further investigation that likely would not have been on their radar otherwise. For instance, the team identified total hip arthroplasty as a current blind spot with significant potential for future products.

B. AI's Market Pull Function

In terms of market pull (the second area), social media can serve as an ideal playground. AI technologies can foster user innovation through need mining, a technique to identify customer needs or lead users from social media or blog posts [32]. In need mining, a neural network is trained to identify, retrieve, and classify innovative posts on a specific topic. Hence, social media or blog posts can be "crawled" with the goal of developing a list of needs or lead users using neural network classifiers [6], [33], [34]. For example, Kakatkar, Bilgram, and Füller [6] used this approach to identify innovative users in the semiconductor industry. Their study aimed to find end-user needs, lead users (professionals and highly capable hobbyists), and a short list of high-impact problems; it used AI technology to identify lead users via their online activity and to create an initial breakdown of key problem areas highlighted by lead users. Overall, this process helped pinpoint individuals and needs, which might have been impossible with manual research alone.

C. AI's Use to Advance in the Innovation Funnel

The third and fourth areas refer to using feature selection within the innovation funnel to decide on which ideas to proceed with. Feature selection is beneficial because once many ideas are in the funnel, decision-making becomes a complicated endeavor when using only conventional methods. Kakatkar, Bilgram, and Füller [6] describe a relevant case study, in which the features of ideas submitted to an ideation campaign were clustered through a neural network. Additionally, grouped idea features can serve as the basis for further development through this feature selection process. The case study's ideation competition for chocolate bars had 1000 participants from 60 countries, with 550 ideas submitted. This AI-based identification helped spotting features, which led to more positive ratings or higher sales.

AI technology can also be used to systematically analyze user feedback. It is possible to enable AI recognition of affective states, such as emotions at scale, using human data (video, physiological, or text). Affective computing can allow empathic products, services, and environments to be created [35], [36], and AI technology can assist humans in continuously monitoring and improving customer satisfaction.

D. AI as a Contributor to New Product Development

The fifth area contributes directly to new product development at its core. AI technology can generate novel and innovative designs. Here, different data sources (e.g., images or audio data) can be used as input information. Generative adversarial networks allow alternative designs to be created through a simultaneous training of models, in which a generator creates images that look real, and a discriminator learns to distinguish between real and fake information [37]– [39]. With this approach, generative algorithms can search massive sets of possibilities—a task no human could undertake [24]. Designers can then detect novel and innovative designs and alter their designs' constraints and characteristics. This process allows alternative opportunities for business to be discovered quickly and easily.

SECTION IV.

AI as an Outcome of the Innovation Process

These five examples highlight AI's potential in companies' innovation management and new product development practices. AI can serve in new roles alongside companies' established processes, which offers significant potential but also poses many challenges.

Thus far, we have described how AI can enable innovation, looking at AI technologies as an input factor; it can revolutionize idea management systems, general creativity, and how lead user innovation takes place. However, ethical and security considerations also play a key role in terms of responsible research, responsible innovation, and AI technology usage [40].

AI technologies are not only an input for other innovations' process, but also an innovation process outcome. As such, they are the result of the commercialization process of research and development activities across a diversity of computer science fields. While AI research expands across scientific disciplines, the number of possible applications (innovation outcomes) is also quickly expanding.

As it happens with scientific developments, the commercialization options of AI research are quickly expanding. As an innovation outcome, it is not surprising that there is an exponentially growing number of startups that build their value proposition around an advance in AI research (e.g., new deep learning technique, new visual recognition or computer vision algorithm, or a novel combination of existing technologies). Similarly, AI researchers in industry and academic settings are seeing the potential of creating spin-offs to explore the potential promising applications.

The digital nature of AI technologies introduces interesting nuances in the commercialization process. For instance, some of the AI research that occurs in the academic setting is difficult to patent; thus, often the conventional processes of technology transfer do not fully fit. The potential risk (at least for public universities or research centers) is that most of the economic gains of AI as an innovation outcome escape unnoticed from the public research context. A patch to this potential problem is to define up-front university-industry collaborations for joint research, asking for an active contribution from industry to support the research activities (while respecting the researchers independence and the necessary ethical considerations).

Another effect of the digital nature of AI is that the business models of the startups or research spin-offs share the challenges of software business models. While it is not difficult to find a first application, it is hard to build a clear value proposition (that alleviates a problem worth solving), and even harder to scale it up and capture value. For this, exploring options to partner up with other AI startups exploring similar industries or application areas (in similar innovation ecosystems) seems to be an effective path to cross the bridge to having a solid business model.

Fig. 5 provides a final overview of our introduced view of AI as an originator and a facilitator. These perspectives can be linked to key areas of innovation research, which is discussed in the Section V.

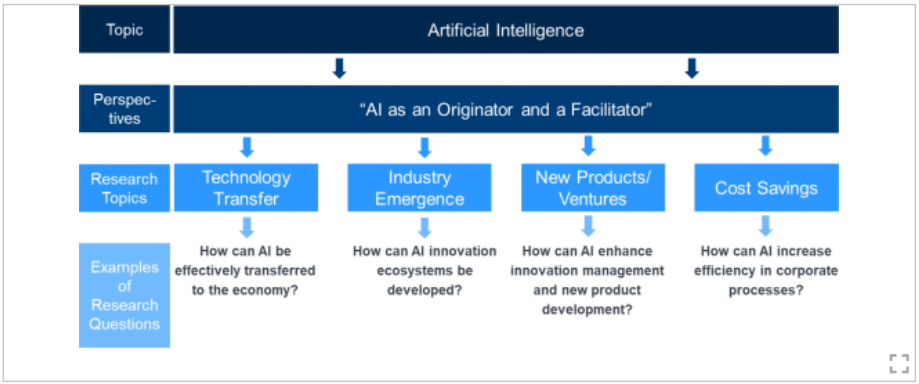

Fig. 5.
AI links to research questions in innovation research. (Source: authors' elaboration).

SECTION V.
Directions for Future Research

AI research, from the management science perspective, remains at its inception. There is a significant potential (and need) for future research, especially in uncovering and creating new ideas at the firm level. AI-driven applications can be used for information searches, idea generation, and value creation.

Many of these new research opportunities create questions on how to ensure data access for startups and on small and medium-sized companies as the basis for these activities. In addition, several competing machine learning approaches must be analyzed to determine which fits best; for this, interdisciplinary research approaches are necessary.

Another area for future research is organizational design, particularly looking at AI's impact on structures and decision processes in organizations—especially in new ventures—which are emerging at a rapid rate. Here, the balance of automated, augmented, and human decision-making might play a key role in future research endeavors in combination with the question of decision systems' influence on decision-making in general.

Finally, the use of AI technologies offers potential to exploit new ideas through selling and scaling activities. In the context of open innovation, this is not only a new phenomenon, but also a different one. For instance, new customer engagement with different types of bots might have interesting impacts to further analyze. Hence, future research might investigate both opportunities and risks associated with the use of multiple overlapping AI systems in order to automate organizational processes or even how algorithms might manage organizations themselves.

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