(03-030) - Designing the Future 5.0: Challenges and Opportunities of Artificial Intelligence in the Product Design and Development Process

Ramos-Calderón, Teresa [1]; Ávila-Gutiérrez, María Jesús [1]; Lama-Ruiz, Juan Ramón [1]

[1] Universidad de Sevilla

In the context of technological evolution and Industry 5.0 (I5.0), with a focus on Artificial Intelligence (AI), significant challenges and opportunities arise for the design and development of products. The growing globalization of the market demands companies to be agile, sustainable, and resilient. Therefore, this work addresses the connection between AI and product design from the perspective of Industrial Design Engineering.

The study is based on documentary research that examines the implementation of AI in the Product Design and Development Process (PDDP). It explores not only the possibilities and resources associated with AI, but also the methods and strategies applied throughout all phases of the process.

The findings reveal that AI poses ethical and technical challenges, while also offering transformative opportunities, proving key to tackle contemporary challenges in product design. Despite its complexity, AI enhances creativity and expedites the design process. Addressing ethical and technical challenges is crucial to fully harness the transformative potential of AI in product design and development, emphasizing its pivotal role in I5.0.

Keywords: Product Design; Industrial Design Engineering; Artificial Intelligence (AI); Smart Manufacturing; Industry 5.0 (I5.0)

Diseñando el Futuro 5.0: Retos y Oportunidades de la Inteligencia Artificial en el Proceso de Diseño y Desarrollo de Productos

En el contexto de la evolución tecnológica y la Industria 5.0 (I5.0), con énfasis en la Inteligencia Artificial (IA), se plantean importantes desafíos y oportunidades para el diseño y desarrollo de productos. La creciente globalización del mercado exige a las empresas ser ágiles, sostenibles y resilientes. Por ello, este trabajo aborda la conexión entre la IA y el diseño de productos desde la perspectiva de la Ingeniería en Diseño Industrial.

El trabajo se basa en una investigación documental que examina la implementación de la IA en el Proceso de Diseño y Desarrollo de Productos (PDDP). Se exploran no solo las posibilidades y recursos asociados a la IA, sino también los métodos y estrategias aplicados a lo largo de todas las fases del proceso.

Los resultados revelan que la IA presenta retos éticos y técnicos, y ofrece oportunidades transformadoras, resultando clave para afrontar los desafíos contemporáneos en el diseño de productos. A pesar de la complejidad, la IA potencia la creatividad y acelera el proceso de diseño. Abordar los retos éticos y técnicos es crucial para aprovechar al máximo el potencial transformador de la IA en el diseño y desarrollo de productos, destacando su papel clave en la I5.0.

Palabras clave: Diseño de Producto; Ingeniería en Diseño Industrial; Inteligencia Artificial (IA); Fabricación Inteligente; Industria 5.0 (I5.0)

Correspondencia: Teresa Ramos-Calderón / tramos@us.es

1. Introduction

In the context of the so-called information age, where the role of ICT and digital technologies is key (Pilloni, 2018), the origin of the technologies associated with Artificial Intelligence (AI) is located around 1950. The passage of time and important technological advances are gradually positioning “machines” at the center of the sociotechnical system, as part of the so-called contemporary knowledge society (Bednar & Welch, 2020).

The technological infrastructure of Industry 4.0 (I4.0) is strengthened in the 21st century by integrating various technological enablers, such as cyber-physical systems, big data, blockchain, cloud computing, digital twins, additive manufacturing, virtual reality, collaborative robotics, artificial intelligence, among others (Maddikunta et al., 2021; J. Zhou et al., 2018). This accelerates the arrival of the Industry 5.0 (I5.0) paradigm with the human-centricity approach, which proposes combining human capabilities with the recent skills acquired thanks to new technologies (Nahavandi, 2019). The desired manufacturing systems are smart, resilient, sustainable and human-centered (Fraga-Lamas et al., 2021). These recent changes have had a significant impact in areas such as Industrial Design (Chapuis et al., 2013).

I5.0 proposes taking advantage of the creativity of human beings in collaboration with intelligent machines (Goujon et al., 2024), making use of global networks in real time to guarantee coordinated and complex processes (Ghobakhloo et al., 2023). In particular, the implementation of AI as a tool in Product Design presents different opportunities to establish synergies and facilitate processes in a constructive way (T. Zhou et al., 2022). Numerous utilities, such as making decisions based on defined patterns and criteria, estimating variables using predictive models and generating images, among others, can be of great help in the Product Design and Development Process (PDDP). However, with the proliferation of AI-based tools, new legal and ethical challenges also arise for professionals and companies (Dhirani et al., 2023).

Among diverse definitions, AI can be broadly defined as a branch of computer science, focused on the study and creation of systems that successfully recreate processes linked to human intelligence, such as learning, reasoning, responding to perceived stimuli or decision making, among others. To do this, this technology applies different algorithms and mathematical models based on the analysis of large amounts of data. For this reason, AI is frequently associated with the specific technologies that support it in the context of I5.0, such as data mining, machine learning, neural networks or deep learning (Guo et al., 2020).

Issues such as smart manufacturing (Bi et al., 2021; Ivanov, 2022), and mass customization through the creation of personalized products (Adel, 2022; Aphirakmethawong et al., 2022), are recent challenges and lines of research that currently arouse great interest among the academic and industrial community (Ordieres-Meré et al., 2023). In this sense, the possibilities of AI are numerous from the perspective of Industrial Design Engineering and Product Development (Deng et al., 2010). Lee (2021) states that AI can improve social sustainability in product design. And for his part, Ghoreishi (2020) explores the possibilities of technologies associated with AI for the Circular Economy. With specific application cases, different authors who implement AI as a generative design tool will be presented in this work, showing its transformative potential (Aphirakmethawong et al., 2022; Matejka et al., 2018; Yoo et al., 2021).

This article has been structured according to the specific objectives defined in this work, and it is summarized below for its understanding. Starting from a brief contextualization of AI in relation to I5.0, the specific objectives of the study are outlined. Section 3 presents the literature review process, focused on the contribution of AI as an applied tool in the PDDP according to the vision of different authors. Next, the theoretical framework of AI in the field of Product

Design is developed and its uses and application cases of interest are discussed. Section 4 describes the main challenges and limitations, pointing out important considerations in the technical, ethical and legal dimensions of AI as a design tool. Consequently, a methodological model to support the early stages of the PDDP with applied AI tools is proposed. Finally, the conclusions drawn from the study are summarized to promote the responsible use of AI as a design tool to make the most of its transformative potential.

2. Objectives

In relation to the object and scope of this work, it must be said that this work is part of a research on Product Design applying AI in the context of I5.0, with emphasis on Artificial Generative Intelligence and generative design. The state of the art carried out from the review of current articles and studies reveals the rise of technologies associated with AI, and in turn it has made it possible to detect a lack of methodological analysis and approach in the early phases of the PDDP on integration of these technologies, with diffuse guidelines regarding the appropriate tools and methodologies from the perspective of Industrial Design.

Therefore, the purpose of this work will be to fill this gap, presenting the challenges and opportunities associated with these technologies through documentary research with a critical approach. The review process is detailed in the following section, contemplating a time horizon from the year 2000 to the present.

The following are established as particular objectives:

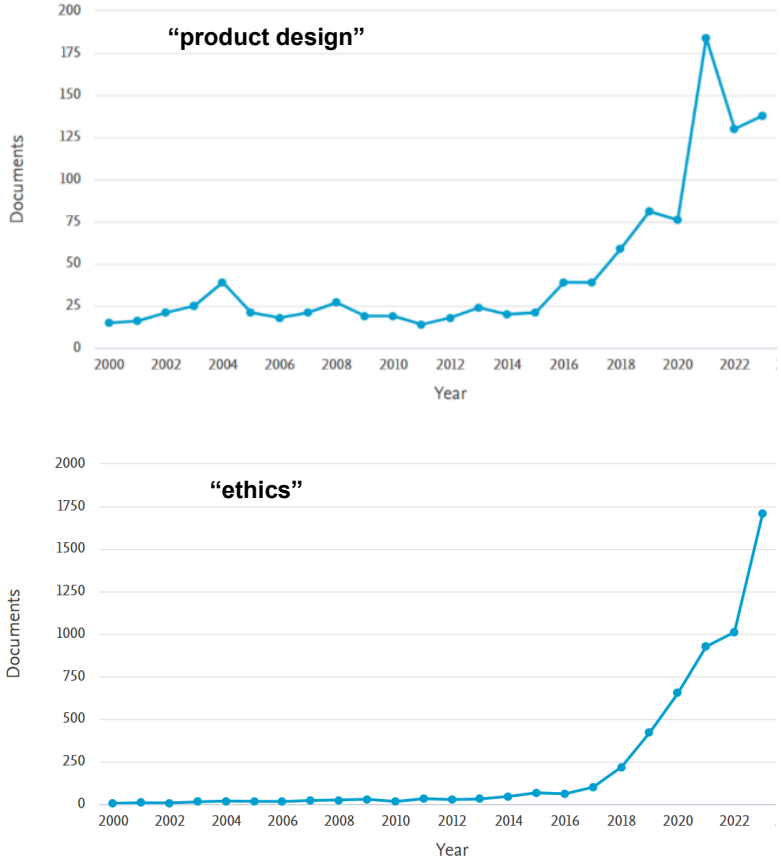
- O1. Corroborate the growing interest in AI as a new tool for product design;
- O2. Present the advantages and opportunities of AI in the design process, allowing to optimize and facilitate specific phases;
- O3. Analysis of the challenges and limitations that currently exist with a critical approach, as points of improvement in the development of these technologies;
- O4. Proposal for a methodological model to support the application of these technologies in a responsible and ethical manner, allowing synergies between human and artificial intelligence.

All these objectives are developed under the human-centricity approach, one of the pillars of the I5.0 paradigm.

3. Review Methodology

Considering the horizon limited between the year 2000 and 2023, a total of 1,084 publications were identified that responded to the search [“artificial intelligence” OR “AI” AND “product design”] in the area of Engineering. As shown in Figure 1 (a), the search in the Scopus database provides evidence of the growing interest in the connection between both concepts. Starting in 2015, the increase in research efforts begins according to the number of annual publications. This growth trend continues to this day, evidencing the increasing interest in AI as a new tool for product design, in reference to O1. The graph in the same period is also shown for the search [“artificial intelligence” OR “IA” AND “ethics”] in the area of Engineering, Figure 1 (b). The increasing trend of the graph in this second search, is much more abrupt and limited in time. This demonstrates the social need for reflection on the concerns and ethical aspects associated with the implementation of AI currently. This relates to the third of the defined objectives and will be discussed in section 5.

Figure 1 (a): Evolution over time of published documents in Scopus, for "product design" (years, documents). Figure 1 (b): Evolution over time of published documents in Scopus for "ethics" (years, documents). Source: Scopus.



The development of the technologies that support AI nowadays has occurred in a short period of time and in a diffuse manner among a multitude of specific applications, which justifies the limited temporal horizon in which the scientific literature of interest is found. Research in relation to these areas remains subject to a multitude of changes, since advances continue to be made at the same time. Furthermore, it is confirmed that the implementation of AI from the perspective of Product Design is a poorly explored area, which is increasingly attracting greater interest.

The bibliographic review has been carried out using Scopus as a database. In this work, contributions in the form of scientific articles, conference proceedings, books and book chapters are considered, in a time horizon limited between 2000 and 2024. The most recent publications, the most relevant for citations in Scopus and referred to the area of Engineering, were prioritized.

Regarding the identification of keywords, in the first phase the comparison of terms, synonyms and acronyms associated with the technologies enabled by AI in the context of I5.0 was proposed. Identified terms such as cognitive computing, data mining, artificial intelligence (AI), machine learning, neural networks, deep learning, can sometimes be confusing in the literature due to their indistinct use.

Search equations were proposed combining the terms "artificial intelligence" or "AI" with the terms "product design" and "ethics" to alternatively find publications and results that address

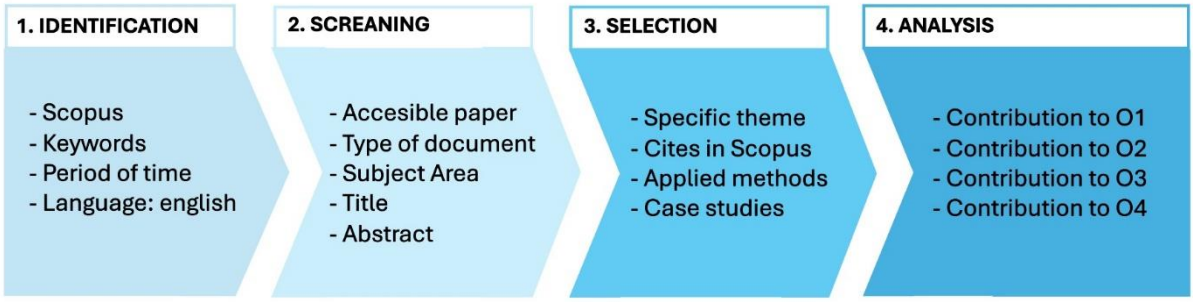
the intersection between both concepts. Table 1 shows the main search equations that were used, along with the results obtained in the Scopus database. This information contributes to once again highlighting the need for research into the interaction between these areas.

Table 1: Main searching equations and results obtained in Scopus. Source: own creation.

Searching equations	Result for tittle, abstract, keywords	Results for tittle
["AI" OR "artificial intelligence" AND “product design”]	1986	29
["AI" OR "artificial intelligence" AND “ethics”]	5976	417
["AI" OR "artificial intelligence" AND “product design” AND “ethics”]	21	1

Figure 2 shows the phases followed in the methodological review process, finally having a total of 120 identified publications. From the sample, a set of 60 references was included in the present study, extracted according to selection criteria related mainly to the suitability of the topic in relation to product design, and not other areas in the development of the study. In addition, the main searches were complemented with secondary searches based on the references present in previous search results.

Figure 2: Literature searching process. Source: own creation.



4. AI in Product Design

The concept of intelligence associated with a machine, what is known today as AI, was established around 1950, following the impact of the work of Alan Turing, considered one of the fathers of computer science (L. Wang et al., 2019). Since then, advances in the development of cognitive computing have given AI a transformative potential nowadays (Rath et al., 2022). In recent years, the powerful capabilities of enablers such as big data and intelligent algorithms have driven a new paradigm for product design known as “AI-enabled Design” (Zuoxu et al., 2022).

In the field of Product Design, there are application cases with varied uses of AI in the different phases of the PDDP (Kusiak & Salustri, 2007; Tsang & Lee, 2022; F. Zhang, 2022). Among others, we can mention the estimation of product costs (Bodendorf & Franke, 2021); the prediction of industrial parameters based on product design (Khdoudi et al., 2020); the study of user needs regarding design parameters (Y. Wang et al., 2018); and even the quantification of the environmental impact according to design decision making, through predictive data analysis (Wisthoff et al., 2016).

Zuoxu (2022) proposes a cognitive intelligence-enabled product design framework, applicable to industrial environments. Lo (2021) focuses on digital twin technology for product design and development, considering the product life cycle, from design, manufacturing, delivery, use and end of life. Of special interest, as author's contribution, is his comparison between the PDDP under the traditional approach, versus the process assisted by DT technology. There is also research work on AI-assisted design in specific sectors or product typologies, as is the case of Song (2022) for the design of drones. The application of AI also occurs in more creative fields where Generative AI stands out (Thoring et al., 2023; Zhu, 2023).

In terms of application to specific phases or tasks of the design process, various authors have investigated the collaboration between people and AI, being the object of study among others: early ideation and concept evaluation(Camburn et al., 2020), later-stage ideation (Yuan & Moghaddam, 2020), design team management (Gyory et al., 2022), and helping teams solve design problems (G. Zhang et al., 2021). Although it must be said that, as Bartlett & Camba (2024) point out, the application of AI in the design process is not always useful, and it is not obvious given the complexity of the technology and the concerns from ethical, technical and legal perspectives. On the other hand, Zhang (2024) applies AI in design by analyzing shape grammar and simulation based on research data and parameter setting. He claims that AI makes it easier for designers to integrate their cultural values into product design, and also improves the efficiency of cultural and creative product design.

There are different authors who mention the concept of “generative design”. Krish (2011) proposes a generative CAD-based design exploration method for complex multi-criteria design problems. The method proposes the construction of a design genotype with a parametric CAD system based on input data, to vary its parameters randomly within predefined limits, obtaining a set of generated design alternatives. Yoo (2021) researches design engineering that integrates artificial intelligence (AI) into computer-aided design (CAD) and computer-aided engineering (CAE). He proposes a CAD/CAE framework based on deep learning and generative AI in the conceptual design phase. Jang (2021) and Oh et al. (2019) reinforce the focus on generative designs based on topology optimization.

Singh (2012) discusses cognitive design and generative design systems, analyzing five different techniques that enable generative design in algorithmic terms. In this sense, there is literature on the development and application of systems and algorithms in relation to product design (Berisha & Lobov, 2021), but these focus on specific aspects of the software and not on the methodological approach for the implementation of AI as a design tool itself. Furthermore, Singh (2012) highlights the need for an integrated generative design framework to improve support of design exploration for human designers. Kallioras (2020) mentions the application of generative design as a designer assistance tool for prototyping in sectors such as product manufacturing, automotive, and aerospace. He proposes a methodology for

Generative Design called DzAIℕ, based on an algorithmic architecture that combines topology optimization and deep learning methods.

Matejka (2018) presents a suitable example of applying AI as a design tool. The AI-assisted design of a product, desktop monitor support, is addressed to demonstrate the usability and usefulness of the Dream Lens system, describing the generation process, as well as the results obtained, a large set of generatively designed data that is filtered for the final definition of design alternatives. As a reference to the above, Table 2 presents the most relevant studies in the analyzed sample, which have successfully applied AI as a design tool, demonstrating the versatility and transformative opportunities it provides in Product Design. The usefulness of each study in relation to the objectives of this work is also assessed.

Table 2: Summary of representative AI application cases as a design tool. Source: own creation

REFERENCE	DESCRIPTION	O1	O2	O3	O4
(Yoo et al., 2021)	Integrating deep learning into CAD/CAE system: generative design and evaluation of 3D conceptual wheel	X	X	X	
(Matejka et al., 2018)	Dream Lens: Exploration and Visualization of Large-Scale Generative Design Datasets	X	X		X
(Krish, 2011)	A practical generative design method	X	X	X	
(Krahe et al., 2020)	Deep Learning for Automated Product Design	X	X		
(Bartlett & Camba, 2024)	Generative Artificial Intelligence in Product Design Education: Navigating Concerns of Originality and Ethics	X	X	X	X

Once the opportunities that are being explored around AI in Product Design have been described, as well as notable application cases, in next section the technical, ethical and legal considerations that currently limit these technologies are analyzed.

5. Challenges and limitations of AI

Diverse authors maintain the transformative potential of AI as an enabler of I5.0 in a multitude of contexts, as Industrial and Product Design (Yüksel et al., 2023). To successfully guarantee the inclusion of these new technologies, they must be implemented based on ethical and regulatory standards. Currently, ethical policies and standards on the use of AI are still under development, and there is no consensus between different territories, which makes it difficult to establish a clear and robust legal regulatory framework. This increases the complexity of use, with the risk of committing privacy and ethics violations that must be resolved (Dhirani et al., 2023).

In this sense, the concerns that have been raised about the impact on society of the proliferation of AI have led to the emergence of a large number of frameworks and policies to improve and regulate conditions with respect to values such as justice, accountability and transparency, in particular, of AI-based services and products (Toreini et al., 2020). Different authors analyze AI frameworks and standards (Fjeld, 2020; Toreini et al., 2020), established by stakeholders such as technology companies, professionals, standardization, government agencies, and academic researchers.

Within the field of Product Design, there are already those who are studying the application of AI as a design tool (Buonamici et al., 2020; Koch, 2017; Verganti et al., 2020). Taking a more skeptical stance, Seidel (2019), among others, states that the emergence of autonomous design tools, based in AI, undoubtedly implies that the role of designers is changing.

The potential of AI and the multiple opportunities that arise are undeniable. However, currently with the development of these technologies in progress, this new field also generates important concerns and challenges at an ethical and legal level for designers, as occurs in design assisted by generative AI tools (Bartlett & Camba, 2024) and in creative fields (West & Burbano, 2020). As a contribution to this work, according to the documentary research carried out, three specific dimensions are proposed to be considered in the implementation of AI as a design tool: technical dimension, ethical dimension and legal dimension.

- Technical dimension

The very nature at a technical level of this type of technological enablers implies limitations regarding the advantages and opportunities that AI can provide. Therefore, it is essential for those who intend to apply AI-Assisted Design tools to know the internal and computer functioning of the available resources. Currently, the input data for AI and machine learning models are decisive in the process of generating results as output data (Rath et al., 2022). It should be noted that the use of free versions of AI-based programs generally implies that the results will be public material, so the AI generates images that can be considered explicitly open source according to its terms of service.

Consequently, users of this type of tools will not be able to generate their own content, as the results are part of the open-user community. Among the technical considerations, it should be said that since these are open learning networks with interaction of multiple users, the same output image could be obtained by more than one user; or the results may be very similar to existing and protected works and designs, whose images have been included as input data for the system. In this sense, the Adobe company has proposed an interesting alternative. Its Firefly AI model is based on training using “Adobe Stock images, openly licensed content, and public domain content whose copyright has expired” (Adobe, 2024).

This type of approach in the development of AI-based technologies provides Product Design, as well as other creative fields, with a hopeful vision of the technical improvement of AI as a design tool, and the solution to various ethical and legal conflicts. It is expected that these types of lines will continue to be developed by the experts involved, providing new transformative possibilities for future AI, which also resolves the various ethical concerns raised (Bartlett & Camba, 2024).

- Ethical dimension

Selecting data for training AI and machine learning models (Kim et al., 2018) may also involve the use of images without permission or compensation to the authors. The lack of control in

the development process of these tools, by the software creation companies, implies the lack of recognition of the authors, designers, artists and even photographers, and can lead to plagiarism or intellectual property problems if not are implemented correctly in the PDDP.

On the other hand, the graphic results generated with AI can respond to certain biases, depending on the input data, as occurs in the representation of human beings where the existence of harmful social biases is already mentioned (Bartlett & Camba, 2024). An example of this is the case of DALL-E and Stable Diffusion, where a research group discovered that this type of AI models learn specific gender and skin tone biases from pairs of images and text on the web (Cho et al., 2024). The DALL-E model overrepresents the gender of people in images based on masculine or feminine stereotypes. Additionally, the DALL-E 2 team found that, as a result of the approach initially applied to sexual content control, output images showing women were reduced, even if they were not related to sexual content (OpenAI, 2024).

Another important aspect is the bias due to westernization of the results generated by AI. Something that limits creativity and the processes of exploring ideas, since design styles can differ depending on factors such as culture, territory, etc. Given the direct implications on product design, it will be crucial to understand cultural variations in design styles, keeping in mind that if AI models over-represent western styles of products, people, environments, etc. uncritical use of these tools could further perpetuate a western bias in design (Bartlett & Camba, 2024). In the case of DALL-E 2, the overrepresentation of “Western concepts” compared to concepts from around the world was also found (Bartlett & Camba, 2024; OpenAI, 2024).

- Legal dimension

There may be legal implications arising from the unconscientious use of AI-based technologies, as it raises questions regarding the originality of the results. The direct link between the input data for the development of AI and the results obtained indicates the crucial importance of the process and the intentionality of the company providing the tool. The results obtained may be very similar to existing and protected works and designs, whose images have been included as input data, which could lead to risks of plagiarism. In this sense, the iconic design of large brands, firms or references can be very present, again limiting originality and diversity in the exploration of ideas.

Another aspect to highlight is that most AI image generating software imposes on users in their terms of service the responsibility of guaranteeing that intellectual property violations are not committed, as is the case of OpenAI and Midjourney (Bartlett & Camba, 2024). So the responsibility for not respecting existing designs and products falls on the user, even though AI companies use images that contain intellectual property of other companies for their models. Therefore, the user will be obliged to confirm whether the generated content is too similar to the recognized intellectual property, and not make use of this result as their original creation. This involves an analysis phase that must be incorporated into the design process when specific AI-based tools are added.

Given the above considerations, the difficult management of rights to results and works generated by AI is understandable. In this sense, the United States Copyright Office states that, according to the copyright law in force, images generated by AI cannot receive rights protection, given the lack of personal creation, as it is considered that “they are not the product of human authorship.” From a Design point of view, AI-based tools can provide transformative opportunities, as long as they are used correctly. It would be advisable to use resources that allow greater control in the process of generating results by AI, so that the input data for software training is based on images and data of your property. On the other hand, it is

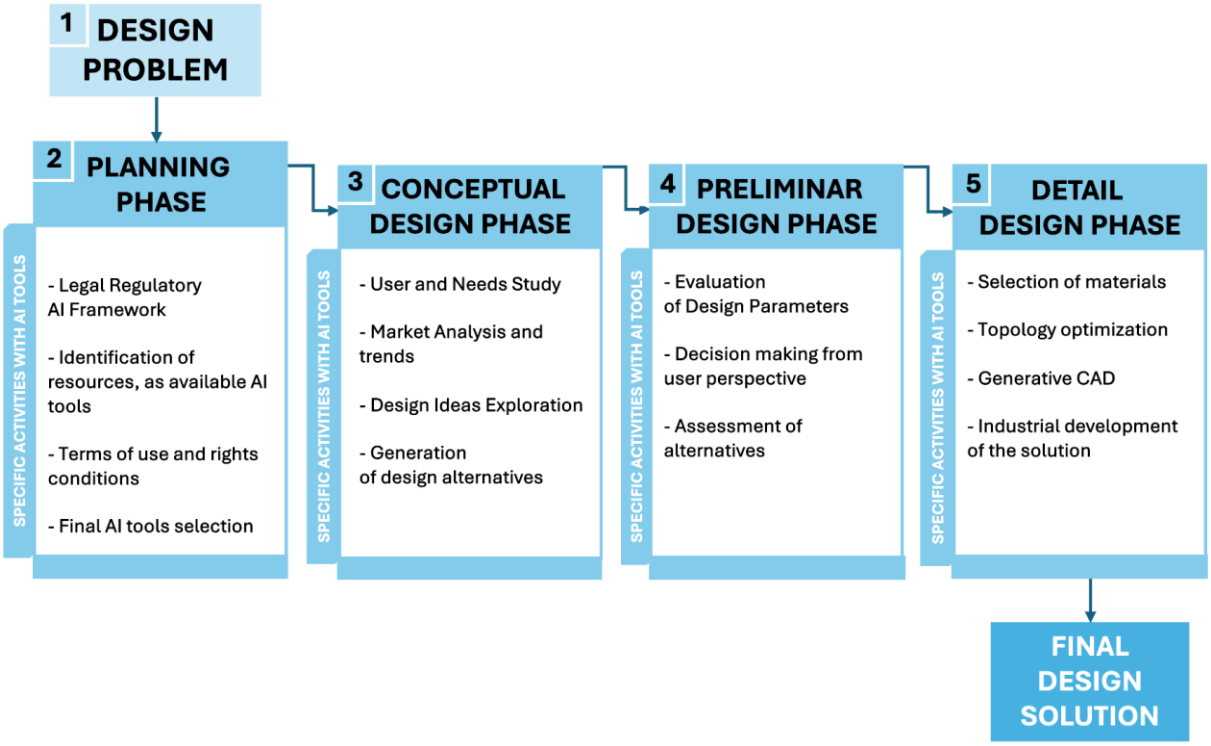
expected that in the near future AI applications will be developed that improve the conditions of authorship, as well as the right to authorize the use of images for their works or products.

The professionals who implement AI tools in the process must work with an established policy that avoids bad practices without discouraging the use of AI as part of the design process. For all this, the potential of AI as a design tool is reaffirmed, based on the fact that it is a support technology that expands human capabilities if implemented correctly. However, human intelligence is essential to guarantee results in line with the requirements of the design brief, avoiding bad practices and excessive reliance on exclusive AI results without a justified PDDP.

6. Methodological model for the integration of AI in Design

As mentioned in previous sections, the implementation of AI in the design process raises multiple opportunities. However, it simultaneously implies challenges in its use and current considerations at a technical, ethical and legal level must be taken into account in the phase in which these technologies are found. For this reason, a proposal for a methodological model has been made for future work in this area, given the lack detected in the literature on studies that address the early stages of the PDDP with the implementation of AI. The model is shown in Figure 3, and integrates 5 phases from the definition of the design model to the final design solution. Special attention should be paid to phase 2, the planning phase prior to the application of AI, for a conscious use of AI tools throughout the process. Every phase in the diagram contains specific activities in the design process that can be supported by AI tools, as shown with presented cases in previous sections.

Figure 3: Proposed methodological model for the PDDP with AI. Source: own creation.



This model is proposed as a reference for the implementation of AI in the PDDP as a design tool. The model begins with the definition phase of the identified design problem. The implementation of AI translates as a previous phase added to the traditional approach, to

consider key aspects related to the three previously defined dimensions. Among other considerations, knowledge of the legal regulatory framework around AI, the tools and resources available, as well as their terms of use and conditions to ensure proper use of them, stands out. The final tools to be used are also established, as well as the data that will be necessary to ensure the quality of the results obtained by AI.

The next phase, Conceptual Design, presents various specific activities that can be optimized by AI, such as the study of needs and users; market and trend analysis; the exploration of design ideas, and the generation of alternatives. Next, the Preliminary Design phase may include the evaluation of design parameters; decision-making from the user perspective; and the evaluation of generated alternatives, among others. Finally, the Detail Design phase is related to generative design applied to CAD and even CAM to detail product development. Material selection and topological optimization are phases where AI has a place to improve process efficiency.

This proposal, from a broad vision, should be adapted based on the formulated design problem or the specific objectives for the PDDP. It is expected that the model can serve as a reference for design professionals who intend to implement AI as a tool from a broad and ethical vision. On the other hand, it will also be useful for references in design education, for whom it enables a deep reflection on the capabilities of AI, as well as the drawbacks and advantages it presents today for future generations of professionals in this field, who are in training currently.

7. Conclusions and future lines of research

In the context of I5.0, one of the enablers that has generated the most interest is Artificial Intelligence. Despite having its beginnings in the 20th century, today this technology is in an incipient stage of development, offering multiple opportunities in a variety of areas. Concerning Product Design, competitiveness and high market demands have promoted AI as a powerful tool for design, allowing to improve workflows, creativity in the inventive process, optimization of times, and even improve the design process.

However, the implementation of AI in the PDDP is so far removed from conventional design methods that it should not be applied without prior knowledge of the field, as well as a clear usage policy. As long as it is used based on certain ethical, technical, and legal considerations, AI can also improve design creativity and efficiency. Therefore, the purpose of this article is to clarify key questions about AI as an applied tool, as well as to present a critical approach the opportunities and limitations it represents from the perspective of Industrial Design Engineering.

In this sense, design professionals will find in this work useful considerations for the implementation of AI as a tool from a wide and ethical vision. On the other hand, this article is also addressed to references in design education, for whom it enables a deep reflection on the capabilities of AI, as well as the drawbacks and advantages it presents today for future generations of professionals in design. Future research trends between AI and Industrial Design are proposed, as future research focused on sustainable design, trust in AI and the integration of emerging technologies towards next-generation AI concerning Industrial Design.

References

Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. Journal of Cloud Computing, 11(1). https://doi.org/10.1186/s13677-022-00314-5

Adobe. (2024). Adobe Firefly. Official Website. https://www.adobe.com/es/products/firefly.html

Aphirakmethawong, J., Yang, E., & Mehnen, J. (2022). An Overview of Artificial Intelligence in

Product Design for Smart Manufacturing. 27th International Conference on Automation and Computing: Smart Systems and Manufacturing, ICAC 2022, 1018, 1–6. https://doi.org/10.1109/ICAC55051.2022.9911089

Bartlett, K. A., & Camba, J. D. (2024). Generative Artificial Intelligence in Product Design Education: Navigating Concerns of Originality and Ethics. International Journal of Interactive Multimedia and Artificial Intelligence, 8(5), 55–64. https://doi.org/10.9781/ijimai.2024.02.006

Bednar, P. M., & Welch, C. (2020). Socio-Technical Perspectives on Smart Working: Creating Meaningful and Sustainable Systems. Information Systems Frontiers, 22(2), 281–298. https://doi.org/10.1007/s10796-019-09921-1

Berisha, B., & Lobov, A. (2021). Overview and Trends for Application of AI Methods for Product Design. IEEE International Conference on Industrial Informatics (INDIN), 2021-July, 1–8. https://doi.org/10.1109/INDIN45523.2021.9557531

Bi, Z., Zhang, W. J., Wu, C., Luo, C., & Xu, L. (2021). Generic design methodology for smart manufacturing systems from a practical perspective. Part ii—systematic designs of smart manufacturing systems. Machines, 9(10), 1–19. https://doi.org/10.3390/machines9100208

Bodendorf, F., & Franke, J. (2021). A machine learning approach to estimate product costs in the early product design phase: A use case from the automotive industry. Procedia CIRP, 100(March), 643–648. https://doi.org/10.1016/j.procir.2021.05.137

Buonamici, F., Carfagni, M., Furferi, R., Volpe, Y., & Governi, L. (2020). “Generative Design”: An Explorative Study. June, 6–10. https://doi.org/10.14733/cadconfp.2020.6-10

Camburn, B., He, Y., Raviselvam, S., Luo, J., & Wood, K. (2020). Machine learning-based design concept evaluation. Journal of Mechanical Design, 142(3), 1–15. https://doi.org/10.1115/1.4045126

Chapuis, Y., Demoly, F., & Gomes, S. (2013). Towards an approach to integrate technological evolution into product design. Proceedings of the International Conference on Engineering Design, ICED, 1 DS75-01(August), 419–428.

Cho, J., Zala, A., & Bansal, M. (2024). DALL-EVAL: Probing the Reasoning Skills and Social Biases of Text-to-Image Generation Models. 3020–3031. https://doi.org/10.1109/iccv51070.2023.00283

Deng, X., Vroman, P., Zeng, X., & Laouisset, B. (2010). Intelligent decision support tools for multicriteria product design. Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, 1223–1230. https://doi.org/10.1109/ICSMC.2010.5642407

Dhirani, L. L., Mukhtiar, N., Chowdhry, B. S., & Newe, T. (2023). Ethical Dilemmas and Privacy Issues in Emerging Technologies: A Review. Sensors, 23(3). https://doi.org/10.3390/s23031151

Fjeld, J. (2020). Principled Artificial Intelligence: Mapping Consensus in Ethical and Rights-based Approaches to Principles for AI. Berkman Klein Center for Internet & Society, 60. https://link.springer.com/chapter/10.1007/978-3-030-29761-9_6

Fraga-Lamas, P., Varela-Barbeito, J., & Fernandez-Carames, T. M. (2021). Next Generation Auto-Identification and Traceability Technologies for Industry 5.0: A Methodology and Practical Use Case for the Shipbuilding Industry. IEEE Access, 9, 140700–140730. https://doi.org/10.1109/ACCESS.2021.3119775

Ghobakhloo, M., Iranmanesh, M., Tseng, M. L., Grybauskas, A., Stefanini, A., & Amran, A.

(2023). Behind the definition of Industry 5.0: a systematic review of technologies, principles, components, and values. Journal of Industrial and Production Engineering, 40(6), 432–447. https://doi.org/10.1080/21681015.2023.2216701

Ghoreishi, M., & Happonen, A. (2020). New promises AI brings into circular economy accelerated product design: A review on supporting literature. E3S Web of Conferences, 158, 1–10. https://doi.org/10.1051/e3sconf/202015806002

Goujon, A., Rosin, F., Magnani, F., Lamouri, S., Pellerin, R., & Joblot, L. (2024). Industry 5.0 use cases development framework. International Journal of Production Research, 0–26. https://doi.org/10.1080/00207543.2024.2307505

Guo, T., Eckert, R., & Li, M. (2020). Application of Big Data and Artificial Intelligence Technology in Industrial Design Article in. International Journal of Advanced Trends in Computer Science and Engineering, 5(1), 10–14. http://www.aiscience.org/journal/ijeecshttp://creativecommons.org/licenses/by/4.0/

Gyory, J. T., Soria Zurita, N. F., Martin, J., Balon, C., McComb, C., Kotovsky, K., & Cagan, J. (2022). Human Versus Artificial Intelligence: A Data-Driven Approach to Real-Time Process Management During Complex Engineering Design. Journal of Mechanical Design, 144(2). https://doi.org/10.1115/1.4052488

Ivanov, D. (2022). The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. International Journal of Production Research, 61(5), 1683–1695. https://doi.org/10.1080/00207543.2022.2118892

Jang, S., Yoo, S., & Kang, N. (2021). Generative Design by Reinforcement Learning: Enhancing the Diversity of Topology Optimization Designs. CAD Computer Aided Design, 146. https://doi.org/10.1016/j.cad.2022.103225

Kallioras, N. A., & Lagaros, N. D. (2020). DzAI𝕟: Deep learning based generative design. Procedia Manufacturing, 44(May), 591–598. https://doi.org/10.1016/j.promfg.2020.02.251

Khdoudi, A., Masrour, T., & El Mazgualdi, C. (2020). Using Machine Learning Algorithms for the Prediction of Industrial Process Parameters Based on Product Design. Advances in Intelligent Systems and Computing, 1104 AISC, 728–749. https://doi.org/10.1007/978-3-030-36671-1_67

Kim, D. H., Kim, T. J. Y., Wang, X., Kim, M., Quan, Y. J., Oh, J. W., Min, S. H., Kim, H., Bhandari, B., Yang, I., & Ahn, S. H. (2018). Smart Machining Process Using Machine Learning: A Review and Perspective on Machining Industry. International Journal of Precision Engineering and Manufacturing - Green Technology, 5(4), 555–568. https://doi.org/10.1007/s40684-018-0057-y

Koch, J. (2017). Design implications for designing with a collaborative AI. AAAI Spring Symposium - Technical Report, SS-17-01-(April), 415–418.

Krahe, C., Bräunche, A., Jacob, A., Stricker, N., & Lanza, G. (2020). Deep Learning for Automated Product Design. Procedia CIRP, 91(March), 3–8. https://doi.org/10.1016/j.procir.2020.01.135

Krish, S. (2011). A practical generative design method. CAD Computer Aided Design, 43(1), 88–100. https://doi.org/10.1016/j.cad.2010.09.009

Kusiak, A., & Salustri, F. A. (2007). Computational intelligence in product design engineering: Review and trends. IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews, 37(5), 766–778. https://doi.org/10.1109/TSMCC.2007.900669

Lee, K. (2021). A Systematic Review on Social Sustainability of Artificial Intelligence in Product

Design. Sustainability, 13. https://doi.org/https://doi.org/10.3390/su13052668

Lo, C. K., Chen, C. H., & Zhong, R. Y. (2021). A review of digital twin in product design and development. Advanced Engineering Informatics, 48(March 2021). https://doi.org/10.1016/j.aei.2021.101297

Maddikunta, P. K. R., Pham, Q. V., B, P., Deepa, N., Dev, K., Gadekallu, T. R., Ruby, R., & Liyanage, M. (2021). Industry 5.0: A survey on enabling technologies and potential applications. Journal of Industrial Information Integration, 26(July). https://doi.org/10.1016/j.jii.2021.100257

Matejka, J., Glueck, M., Bradner, E., Hashemi, A., Grossman, T., & Fitzmaurice, G. (2018). Dream lens: Exploration and visualization of large-scale generative design datasets. Conference on Human Factors in Computing Systems - Proceedings, 2018-April, 1–12. https://doi.org/10.1145/3173574.3173943

Oh, S., Jung, Y., Kim, S., Lee, I., & Kang, N. (2019). Deep generative design: Integration of topology optimization and generative models. Journal of Mechanical Design, 141(11). https://doi.org/10.1115/1.4044229

OpenAI. (2024). OpenAI. Official Website. https://openai.com/

Ordieres-Meré, J., Gutierrez, M., & Villalba-Díez, J. (2023). Toward the industry 5.0 paradigm: Increasing value creation through the robust integration of humans and machines. Computers in Industry, 150(May), 103947. https://doi.org/10.1016/j.compind.2023.103947

Pilloni, V. (2018). How data will transform industrial processes: Crowdsensing, crowdsourcing and big data as pillars of industry 4.0. Future Internet, 10(4). https://doi.org/10.3390/fi10030024

Rath, R. C., Baral, S. K., Singh, T., & Goel, R. (2022). Role of Artificial Intelligence and Machine Learning in Product Design and Manufacturing. 2022 International Mobile and Embedded Technology Conference, MECON 2022, 571–575. https://doi.org/10.1109/MECON53876.2022.9752455

Seidel, S., Berente, N., Lindberg, A., Lyytinen, K., & Nickerson, J. V. (2019). Autonomous tools and design: A triple-loop approach to human-machine learning. Communications of the ACM, 62(1), 50–57. https://doi.org/10.1145/3210753

Singh, V., & Gu, N. (2012). Towards an integrated generative design framework. Design Studies, 33(2), 185–207. https://doi.org/10.1016/j.destud.2011.06.001

Song, B., Soria Zurita, N. F., Nolte, H., Singh, H., Cagan, J., & McComb, C. (2022). When Faced with Increasing Complexity: The Effectiveness of Artificial Intelligence Assistance for Drone Design. Journal of Mechanical Design, 144(2), 1–12. https://doi.org/10.1115/1.4051871

Thoring, K., Huettemann, S., & Mueller, R. M. (2023). the Augmented Designer: a Research Agenda for Generative Ai-Enabled Design. Proceedings of the Design Society, 3(JULY), 3345–3354. https://doi.org/10.1017/pds.2023.335

Toreini, E., Aitken, M., Coopamootoo, K., Elliott, K., Zelaya, C. G., & van Moorsel, A. (2020). The relationship between trust in AI and trustworthy machine learning technologies. FAT* 2020 - Proceedings of the 2020 Conference on Fairness, Accountability, and Transparency, 272–283. https://doi.org/10.1145/3351095.3372834

Tsang, Y. P., & Lee, C. K. M. (2022). Artificial intelligence in industrial design: A semi-automated literature survey. Engineering Applications of Artificial Intelligence, 112(March), 104884. https://doi.org/10.1016/j.engappai.2022.104884

Verganti, R., Vendraminelli, L., & Iansiti, M. (2020). Innovation and Design in the Age of Artificial Intelligence. Journal of Product Innovation Management, 37(3), 212–227. https://doi.org/10.1111/jpim.12523

Wang, L., Zhang, H. C., & Wang, Q. (2019). On the Concepts of Artificial Intelligence and Innovative Design in Product Design. IOP Conference Series: Materials Science and Engineering, 573(1). https://doi.org/10.1088/1757-899X/573/1/012095

Wang, Y., Mo, D. Y., & Tseng, M. M. (2018). Mapping customer needs to design parameters in the front end of product design by applying deep learning. CIRP Annals, 67(1), 145–148. https://doi.org/10.1016/j.cirp.2018.04.018

West, R., & Burbano, A. (2020). Ai, Arts & Design: Questioning Learning Machines. Artnodes, 26(26), 1–9. https://doi.org/10.7238/a.v0i26.3390

Wisthoff, A., Huynh, T., Ferrero, V., & Dupont, B. (2016). Quantifying the impact of sustainable product design decisions in the early design phase through machine learning. Proceedings of the ASME Design Engineering Technical Conference, 4, 1–10. https://doi.org/10.1115/DETC2016-59586.pdf

Yoo, S., Lee, S., Kim, S., Hwang, K. H., Park, J. H., & Kang, N. (2021). Integrating deep learning into CAD/CAE system: generative design and evaluation of 3D conceptual wheel. Structural and Multidisciplinary Optimization, 64(4), 2725–2747. https://doi.org/10.1007/s00158-021-02953-9

Yuan, C., & Moghaddam, M. (2020). Attribute-Aware Generative Design with Generative Adversarial Networks. IEEE Access, 8, 190710–190721. https://doi.org/10.1109/ACCESS.2020.3032280

Yüksel, N., Börklü, H. R., Sezer, H. K., & Canyurt, O. E. (2023). Review of artificial intelligence applications in engineering design perspective. Engineering Applications of Artificial Intelligence, 118(April 2022), 105697. https://doi.org/10.1016/j.engappai.2022.105697

Zhang, F. (2022). Design and Implementation of Industrial Design and Transformation System Based on Artificial Intelligence Technology. Mathematical Problems in Engineering, 2022, 1054–1057. https://doi.org/10.1109/ICSECE58870.2023.10263394

Zhang, G., Raina, A., Cagan, J., & McComb, C. (2021). A cautionary tale about the impact of AI on human design teams. Design Studies, 72, 100990. https://doi.org/10.1016/j.destud.2021.100990

Zhang, S. (2024). Exploration of Cultural and Creative Product Design Thinking in the Age of Artificial Intelligence. Applied Mathematics and Nonlinear Sciences, 9(1).

Zhou, J., Li, P., Zhou, Y., Wang, B., Zang, J., & Meng, L. (2018). Toward New-Generation Intelligent Manufacturing. Engineering, 4(1), 11–20. https://doi.org/10.1016/j.eng.2018.01.002

Zhou, T., Xiong, W., Obata, Y., Lange, C., & Ma, Y. (2022). Digital product design and engineering analysis techniques. In Digital Manufacturing: The Industrialization of “Art to Part” 3D Additive Printing. INC. https://doi.org/10.1016/B978-0-323-95062-6.00003-6

Zhu, Z. (2023). Research on artificial intelligence product design method based on product semantics. 2nd International Conference on Computer Graphics, Artificial Intelligence, and Data Processing (ICCAID 2022), 12604 (May 2023), 87. https://doi.org/10.1117/12.2674615

Zuoxu, W., Jihong, L., & Lianyu, Z. (2022). The Evolution, Framework, and Future of Cognitive Intelligence-enabled Product Design. Procedia CIRP, 109(March), 526–531. https://doi.org/10.1016/j.procir.2022.05.289

Communication aligned with the Sustainable Development Goals