Title:
A quantitative analysis of patented Artificial Intelligence (AI)-based CAD tools

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Introduction:
The rapid development of artificial intelligence (AI) is having a disruptive impact in various areas of design in industry, as well as on computer aided design (CAD) tools [5]. Virtually all well-known commercial software is introducing new features based on its usage [6]. The resulting advantages are various and mainly concern greater automation in the design and the increase in design complication and complexity [4].

Several studies in the literature have analysed these impacts, studying the present and hypothetical future functionalities of AI-based CAD tools. Mainly, some studies have analysed how commercial software makes use of AI, e.g. [6], while other studies have analysed the contributions in scientific literature, e.g. [3]. Regarding the object of the analysis, the functionalities of CAD supported by AI were analysed, as well as the repercussions of the introduction of AI-based CAD tools on the design activity, e.g. [1].

However, all of these studies have limitations:

- The considerations presented are not exhaustive, since the number of contributions analyzed is always limited and they were not obtained with a structured and rigorous collection methodology.
- A perspective on the present and future industrial interest towards the development of AI-based CAD tools is missing since many of the considerations obtained concern scientific articles carried out by university researchers.
- The existing studies only consider a few aspects at a time. Therefore, an objective and multi-criteria comparison based on the same documents is missing.
- The obtained results are qualitative, i.e., there is no analysis based on numerical percentages and trends relating to the characteristics and development directions of the AI-based CAD tools.

To overcome these limitations, this study proposes an analysis of the patent literature of AI-based CAD tools, based on a large number of documents, coming from the industry, which have been collected and analyzed in a rigorous and quantitative way. The analysis approach used has been adequately structured in other works (e.g. [8]; [9]) and has been customized in this specific field of application

Methodology:
The patent search was carried out following a step-divided systematic procedure (see Fig. 1):

1. The starting query "((CAD OR (COMPUTER 1D AIDED 1D DEISGN)) AND ("AI" OR (ARTIFICIAL 1D INTELLIGENCE+)))/TI/AB/CLMS" was launched in Orbit DB in title, abstract and claims and

made it possible to identify 817 patents. This query was built including all the keywords that can generally limit the concepts of CAD and AI, which have been linked together by certain logical and proximity operators.

2. The collected patents were automatically filtered based on the priority date, i.e. the filing of the application. Only those from the last 20 years, i.e. from 2003 to today, have been preserved in order to provide an updated overview on the subject.
3. The patents were manually analysed in title and abstract to evaluate their relevance to the topic. The difficulty of circumscribing the latter with queries made this onerous operation necessary. After this analysis, 470 patents have been retained.

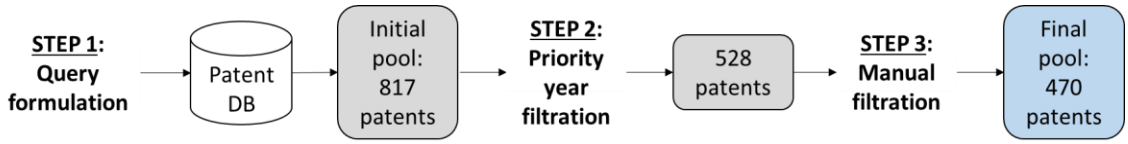

Fig. 1: Patent search methodology.

The patent analysis was performed on the final pool, with the aim of determining the following information relating to the patented AI-based CAD tools:

- Bibliometric analysis of patents, to study publication trends, legal status and geographical origin of patents.
- Competitors analysis, to understand who are the industries of the sector most active in patenting.
- Input and output of the patented AI-based CAD tools, i.e., what the tools require from the input user and the generated products.
- Purposes of the patented AI-based CAD tools, in termini di application field e goals del design for X.

The patent analysis was performed semi-automatically, combining different techniques:

- Automatic analysis of the final pool to determine bibliometric info and competitors analysis, performed using Orbit DB features.
- Automatic content analysis to determine top topics, using Orbit DB functionality.
- Querying the final pool with queries containing keywords related to classifications known in the literature of AI-based CAD tools and CAD in general (e.g. [2], [3]).
- Manual analysis of the patents for new topics to add to known classifications.

Results:

Bibliometric analysis of patents

The results of the bibliometric analysis of the patents (see Fig. 2) have highlighted a markedly increasing temporal trend in recent years (i.e., since 2017). The decrease from 2021 is instead due to the secrecy period, of around 18 months, of the most recent patent applications, which are therefore not indexed in the databases. As far as the legal status of patents is concerned, it can be noted that most of them are active, both as real patents (granted) i.e., that have obtained a positive result in the examination, and as patent applications. Only a few patents have been allowed to lapse. As regards instead the geographical distribution of the after-sites of the applications, we note the prevalence of China, justifiable with the increase in patenting in the country in recent years and in all sectors, and the United States. The other countries that patent are mainly the European ones, albeit detached from the first two.

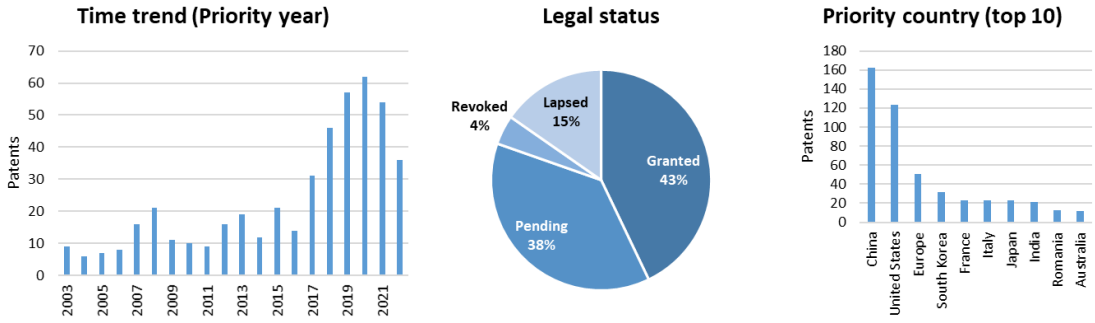

Fig. 2: Bibliometric analysis of the patents about AI-based CAD tools.

Competitors analysis

The analysis of the sector players showed a very heterogeneous distribution since the top 10 hold only 9% of the patents. Furthermore, among the players there are also several universities, especially Chinese, spin-offs, research centres and Strat-ups.

Input and output of the patented AI-based CAD tools

The analysis of the inputs in the patented CAD tools (see Fig. 3) highlighted a predominant reuse of 3D models, for example collected from the cloud and recombined by the CAD itself using AI. The interest is also placed in the analysis of 2D representations, mainly images and drawings. Less considered are instead the requirements and constraints. While the outputs obtained are mainly drawings of new products and measurements of certain characteristics.

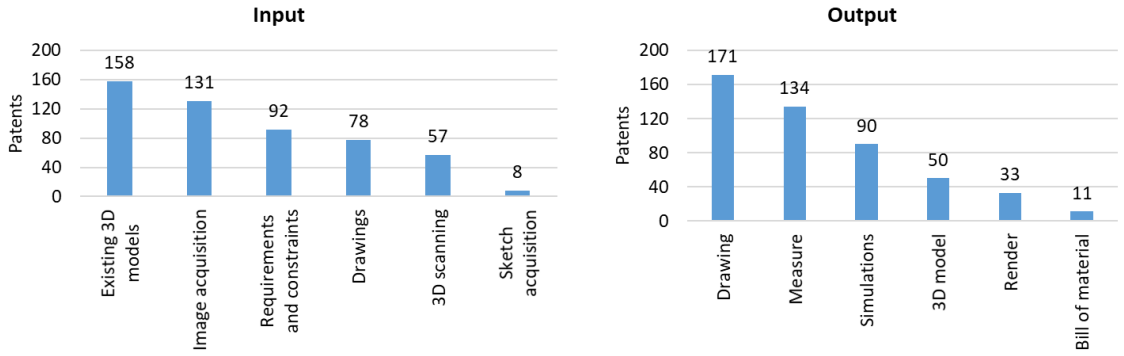

Fig. 3: Inputs and output of the patented AI-based CAD tools.

Purposes of the patented AI-based CAD tools

The purposes for which the patented AI-based CAD tools are conceived are many and varied (see Fig. 4). Among the application fields there are above all the general purpose, architectural, medical and energy plants, even if the distribution is very balanced. As regards the goals of the design for X of the patented AI-based CAD tools, the interest in improving producibility and economic sustainability (cost-reduction) above all emerged. The other goals are rather detached and above all concern product reliability and environmental sustainability.

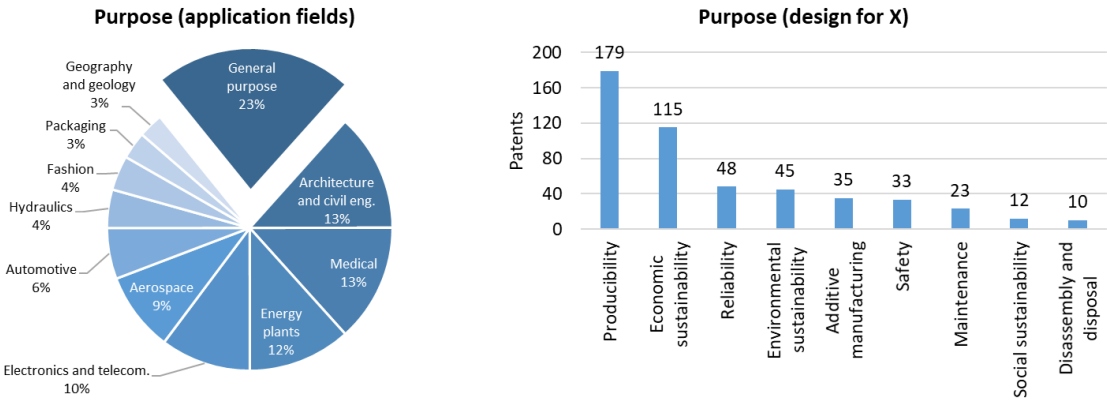

Fig. 4: Purposes of the patented AI-based CAD tools: applications fields and supported goals of "Design for X".

Discussion and conclusions:

Some new considerations, compared to the literature of the sector, can be drawn starting from the results obtained thanks to the patent analysis carried out on AI-based CAD tools.

The bibliometric analysis has highlighted a marked growing interest in recent years towards the patenting of AI-based CAD tools. This evidence is reinforced by the interest in patent preservation and in the vast number of patent applications currently under review. The heterogeneous geographical distribution of patents and the analysis of the players testify to a lively industrial interest in the subject and far from the monopolistic interests of large companies. Which suggests ample room for maneuver for scientific research.

The analysis of the inputs and outputs of the patented AI-based CAD tools has highlighted a more marked interest in reusing existing models and images rather than in creating new models from scratch starting from constraints. The tools themselves are mainly developed to provide technical information to the designer. In particular, going into the merits of these patents, it is clear from their claims that AI is used to speed up the process of supplying technical information to the designer and make it more efficient as the design complexity increases. This evidence confirms what has already been discussed, albeit qualitatively, in the literature, e.g. [7].

The application fields and design purposes supported by the patented AI-based CAD tools are diverse and heterogeneous, given the prevalence towards general purposes and support for design for producibility and sustainability. These results therefore align the development of AI-based CAD tools at an industrial level with the topics very popular in the last period of industry 4.0/5.0 and sustainability, especially environmental product, as hypothesized and prescribed by different studies (e.g. [5]; [6]).

These results should be read in relation to the limitations of this work, mainly related to the number of analyzed documents and the level of detail. The future developments of this work concern an expansion of the documentary pool to include other patents, their comparison with the scientific literature, and a much more detailed and in-depth analysis of the data.

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