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European Patent Office
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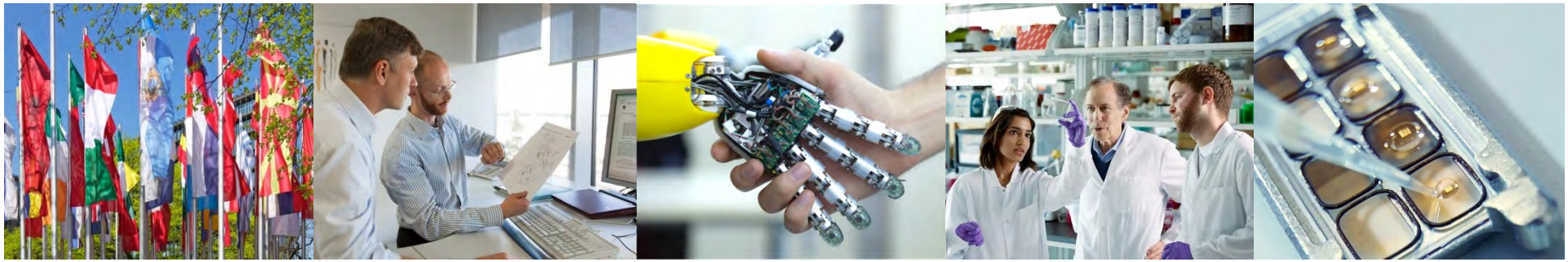
Future and emerging technologies (FETs)

4D Printing



Nigel Clarke (EPO) Judy Ceulemand (EPO) Björn Jürgens CITPIA Andalusia

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- Judy Ceulemans EPO The Hague
  Subject matter specialist, patent examiner
  Senior expert

- Björn Jürgens CITPIA Andalusia Spain patent analyst

- Nigel Clarke EPO Vienna Patent Knowledge research


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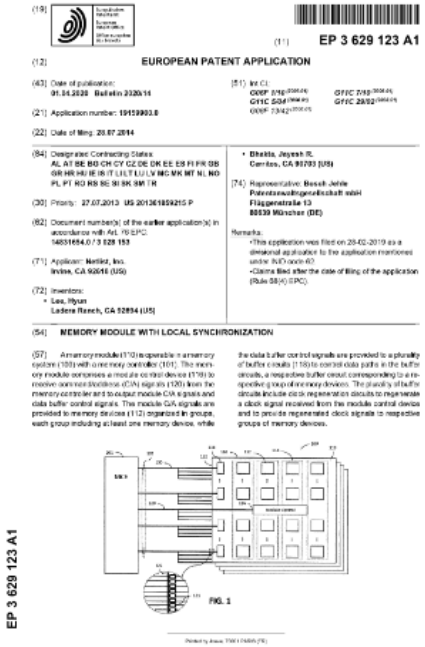
Patent information and landscaping

Patents…

- are documents that **cover technical inventions**
- describe something claimed to be new and thus are **closely linked to innovation**
- are available as **long and short time series** and across **many countries**
- are **publicly available** from patent search platforms like *Espacenet*



(19) EP 3 629 123 A1

(12) EUROPEAN PATENT APPLICATION

(54) MEMORY MODULE WITH LOCAL SYNCHRONIZATION

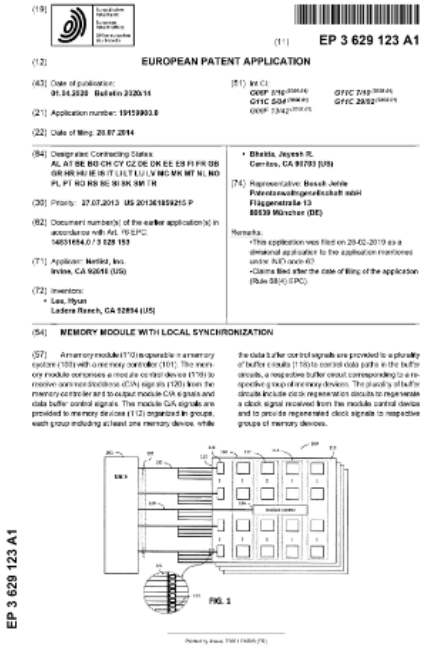
EP 3 629 123 A1

Frontpage of an European Patent Application

Patent information and landscaping

Patents landscaping…

- Also referred to Patent Mapping, Patent Bibliometrics, or Patent Intelligence
- A **snapshot** of the patent situation of a specific technology, either within a given country or region, or globally.
- A **statistical analysis** of patent “big data”.
- Taking advantage of its **structured format**, patent statistics are conducted on a large set of bibliographic patent references with bibliometric techniques.
- Multi-step process, employing **software** and **human intelligence** to review, organize, and extract information from extensive patent search results in a specific technology area.



(19) EP 3 629 123 A1

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FIG. 1

Frontpage of an European Patent Application

Patent information and landscaping

Use of patent landscaping:

- The analysis of patent information gives us a **valuable insight** into the patent activities of **corporations, universities, governments and research institutions** around the world providing a snapshot of a technology field, the so called patent landscape.
- Especially in **future and emerging technologies (FETs)** a patent landscaping is of interest since the patent information offers a basis for analysis where other data is usually scarce.
- **Synthesis of recent past**
- **Snapshot of instantaneous present**
- **“Camera”**

EPO Patent insight reports

- **Engage with business, STEMM, innovation communities**
- **Educational and promotional material**
- **Gain insight and competitive advantages about a specific technological field.**

- **Dedicated webpage on the EPO webportal:**

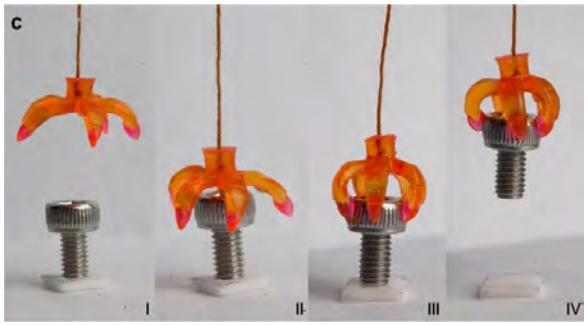
https://www.epo.org/searching-for-patents/business/patent-insight-reports.html

Project background & objectives

- The objective of the present patent insight report is to deliver a patent landscape analysis about 4D printing technologies based on the case study EPO published in their publication “Patents and Additive Manufacturing” (pp 24-27) and the EPO’s Search Matters seminar that included a workshop on 4D printing (https://www.epo.org/news-events/events/conferences/search-matters.html)

What is 4D Printing?

- Four-dimensional (4D) printing is concerned with 3D printed objects that can self-assemble or reshape themselves with **time**. 4D printed products can change shape, colour or size to suit particular applications after first being made by conventional additive manufacturing (AM).
- 4D printing involves creating objects with special single or multi-material components which change in a controlled way either spontaneously or in response to external stimuli.
- In many applications the deformation can be reversible; when the external influence is removed, the component reverts to its original form. The significant difference between 3D and 4D printing is the time dependency of the spontaneous or stimulated change in size, shape or colour. As in relativity theory, time is the fourth dimension.



A time-lapse of an SMP gripper for grabbing and releasing an object

Definition from : Clarke, N. Case study: 4D printing, In: Patents and Additive Manufacturing
Image from: By Qi Ge, Amir Hosein Sakhaei, Howon Lee, Conner K. Dunn, Nicholas X. Fang & Martin L. Dunn -

Search strategy

- The search strategy is based on a **combination of both keywords and patent classification symbols:**
  - The **keywords** relate to **4D printing**
  - The keywords were searched in the **title, abstract or claims** of the patents.
  - The results were then restricted to patents that were classified with either one of the patent classes related to **3D printing**.
- Geographical coverage: **worldwide**
- Document type retrieved: patent documents encompassing **both granted patents and patent applications** before finishing the search and examination procedure
- Timeframe:
  - patents with the first priority year 2010 onwards*
  - till patents published in December 2020 (date of query launch and dataset generation)

* Although the term 4D printing was first coined by TED professor Skylar Tibbits in his February, 2013 speech at the MIT Conference (https://www.ted.com/talks/skylar_tibbits_the_emergence_of_4d_printing) we also included the years 2010-2013 for completeness.

Search Strategy – Relevant patent classification schemes

Symbol & Scheme	Class Definition	Comments
B33Y IPC/CPC	ADDITIVE MANUFACTURING, i.e. MANUFACTURING OF THREE-DIMENSIONAL [3-D] OBJECTS…	Secondary classification scheme which is not complete (only in place since 2016) and should “connect all the dots” in the Additive Manufacturing (AM) field
B29C64 IPC/CPC	SHAPING… ADDITIVE MANUFACTURING…	Dedicated to the shaping of POLYMERS with AM technology, does not cover any material though
B22F10/10 CPC (formerly B22F3/008)	AM … from METALLIC powder - Formation of a green body	Dedicated to the shaping of METAL POWDERS with AM technology, does not cover any material though
B22F10/20 CPC (formerly B22F3/1055)	AM … from METALLIC powder – Direct sintering or melting	

Search Strategy – Relevant Keywords

(4_D W print+) OR (shape W memory) OR programmable OR (residual W strain)

Concept: 4D

AND

..combined with..

(metal+ OR polyme+ OR material+ OR ceram+ OR gel?)

Concept: Materials

+ Truncation replaces any number of characters
? Truncation replaces zero or one character
W Terms adjacent in the order inside the same sentence

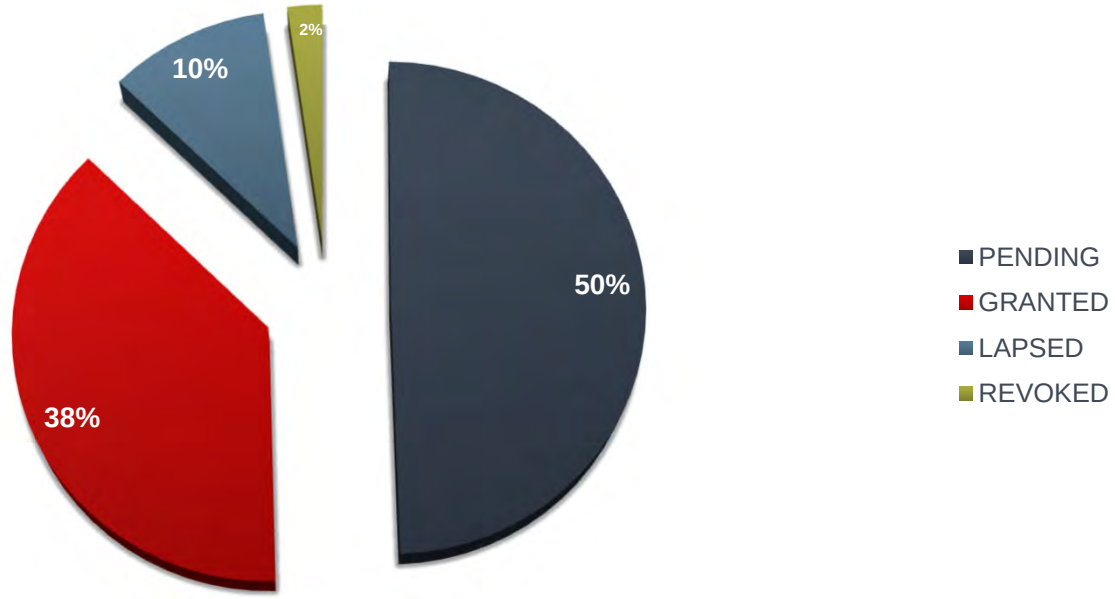
Patent landscape statistics in a nutshell

- 527 patent families*
- 1364 patent documents
- published in 39 countries/jurisdictions
- first filings (priority) in 22 countries/jurisdictions
- 1836 inventors and 315 applicants

* Based on simple patent families. A simple patent family is a collection of patent documents that are considered to cover a single invention. The technical content covered by the applications is considered to be identical. Members of a simple patent family will all have exactly the same priorities.

Patent landscape legal status

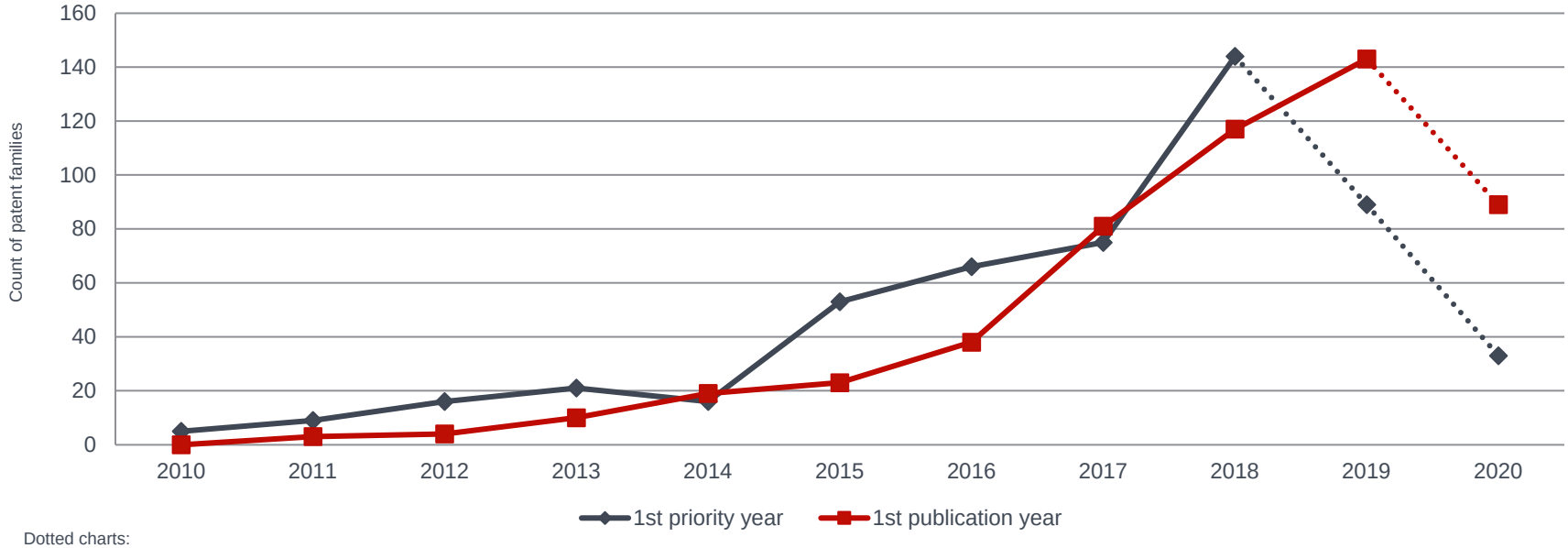
➢ Half of all 4D printing patents are still pending => Clear sign of an emerging technology field!



4D printing patent dataset: 1364 patent documents in 527 families

Evolution - worldwide

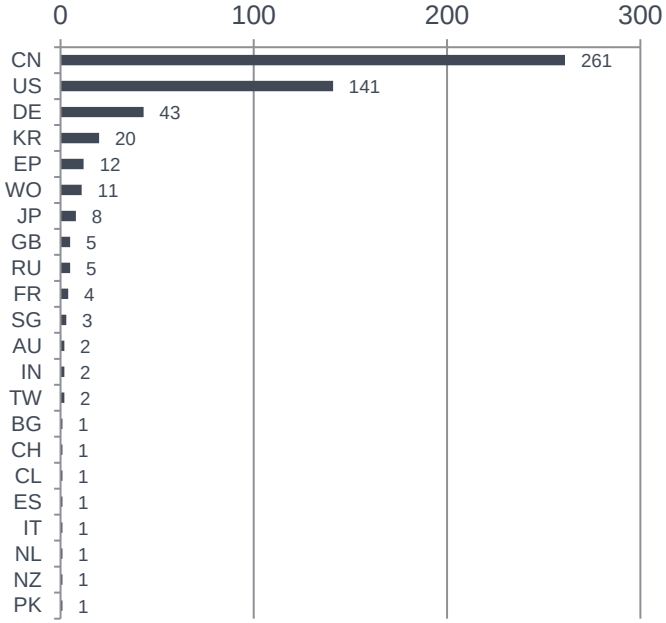
- By analysing the total patenting output over the years we can see if a given technology sector is emerging, stalling or declining.
- In the case of 4D printing we can see that **patenting** (priority filings) **took off in 2014 (in 2015 3x more filings comparing to 2014!)**
- Although 2020 data is not compete (**) it seems that **in 2019 more 4D printing patent applications will have been published than in 2020**



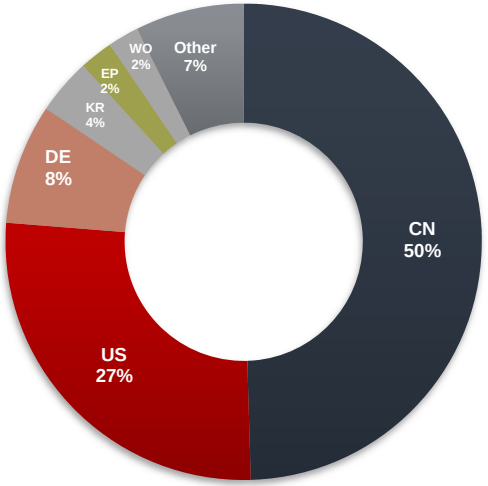
Dotted charts:
* Patent data is incomplete for priority year 2019 and 2020 due to 18 month period till patent is published.
** Patent data is incomplete for published patents in 2020 since the dataset was created in 12/2020

4D Printing: Origins - Countries / jurisdictions with first filings

- The countries where a patent was filed for the first time (the priority patent) are usually the countries where the invention originates and thus can give us information about the geographical origin of innovations.
- For 4D printing related patent applications we identified **22 priority countries in total**. Most patents were first filed in China (50%, mainly by Chinese applicants), followed by the US, Germany and Korea.

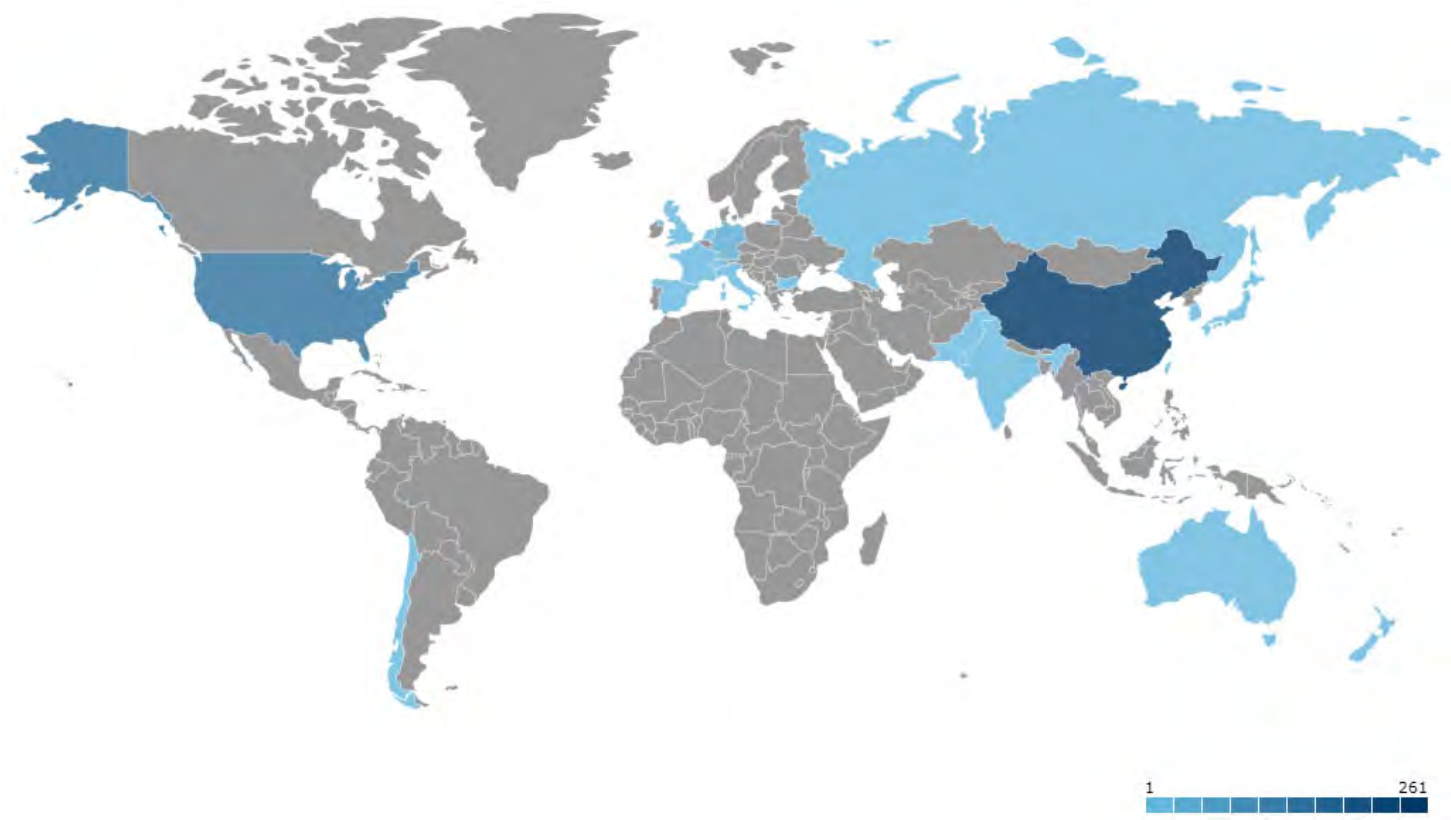


Jurisdictions with priority applications (first priority country)



Distribution of jurisdictions with priority applications (first priority country)

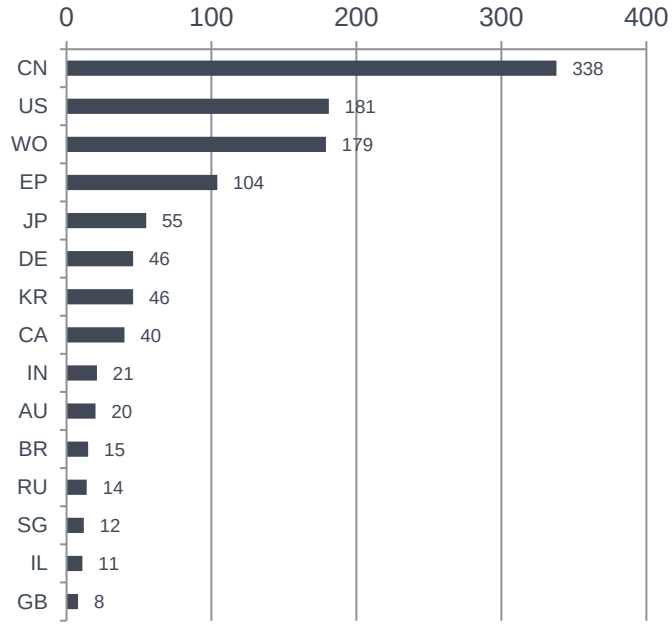
4D Printing: Origins - Countries / jurisdictions with first filings



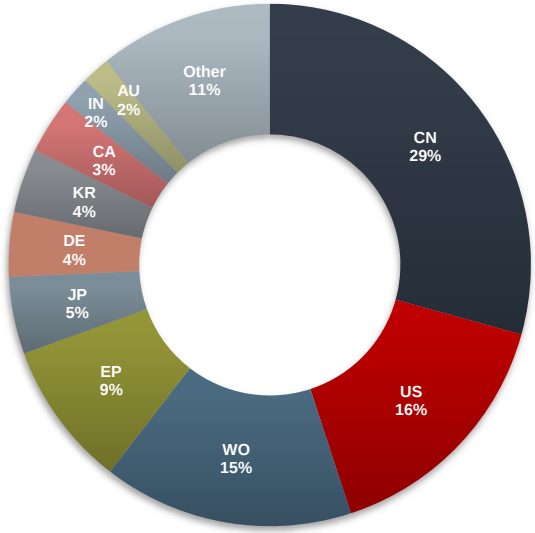
Worldmap with priority applications (without EP and WO) (Source: Orbit)

4D Printing: Markets - Countries / jurisdictions with published applications

- The countries where protection is sought via patent applications are considered as **important markets for a commercialization** of the invention.
- For 4D printing related published patent applications we identified **39 countries** in total, top 5 are publications at the Chinese Office (mostly domestic only), followed by the US, patent applications via the international PCT system, the EPO and Japan.

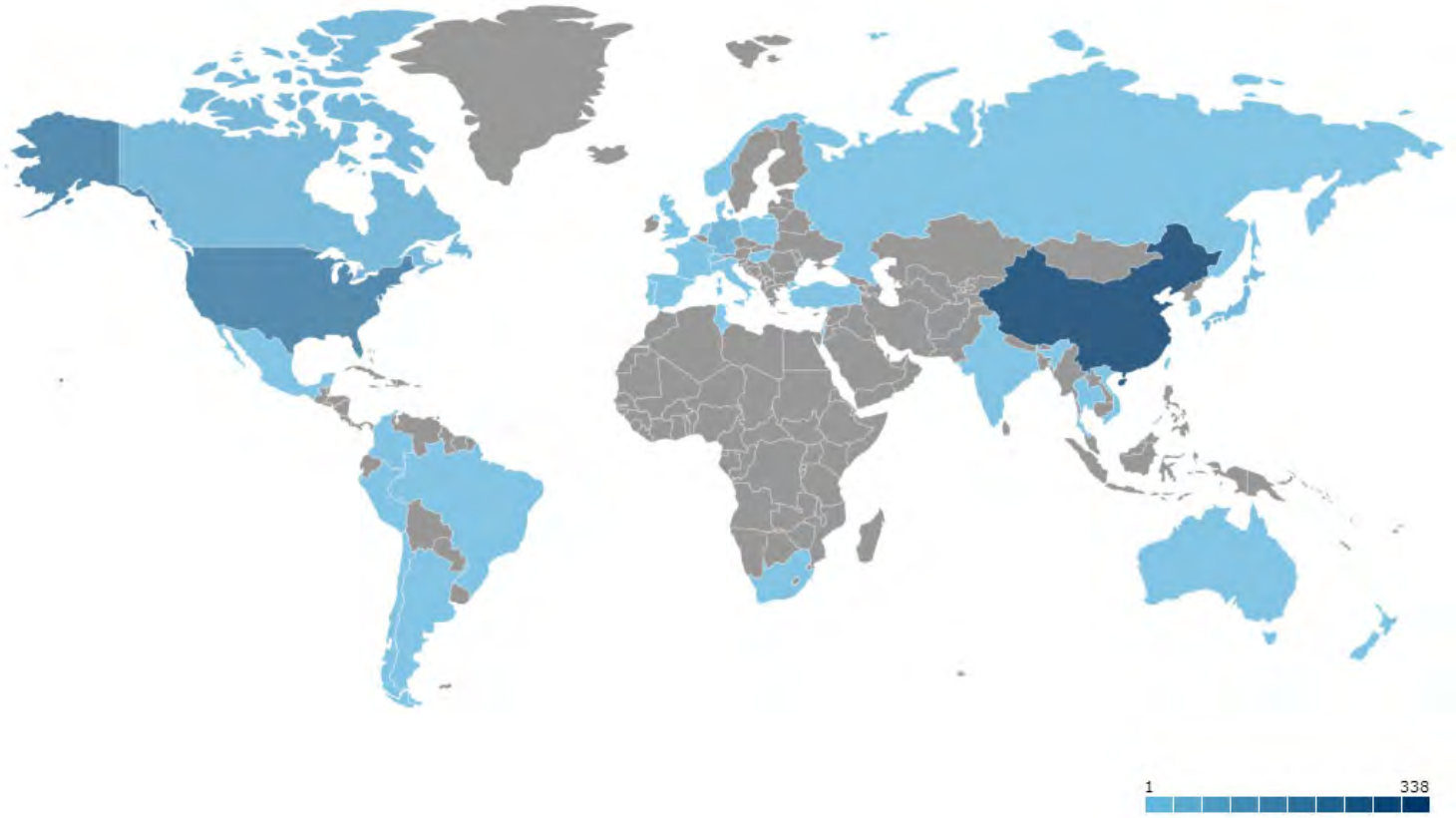


Top 15 jurisdictions with published patent applications



Distribution of top jurisdictions with published patent applications

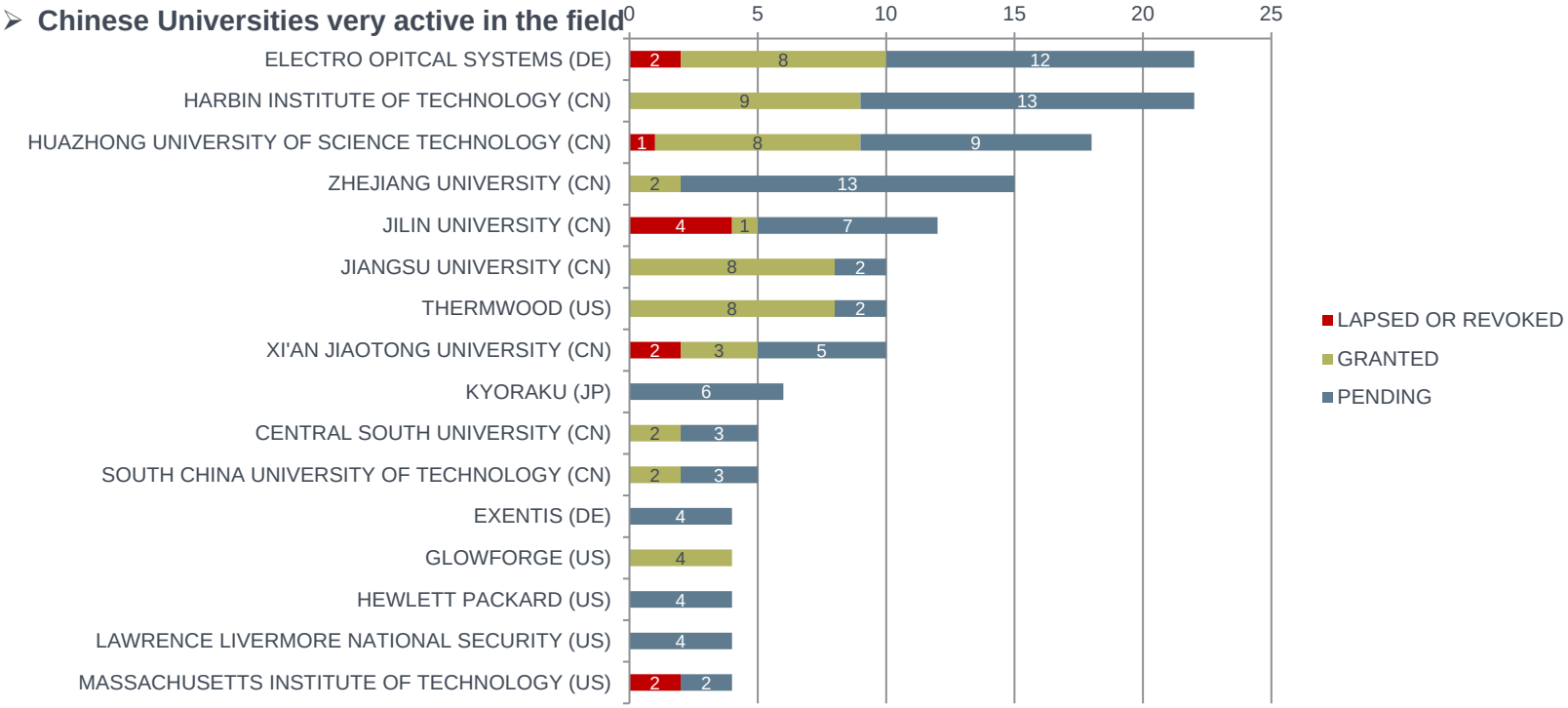
4D Printing: Markets - Countries / jurisdictions with published applications



Worldmap with published patent applications (without EP and WO) (Source: Orbit)

Top players worldwide published patent applications & portfolio legal status

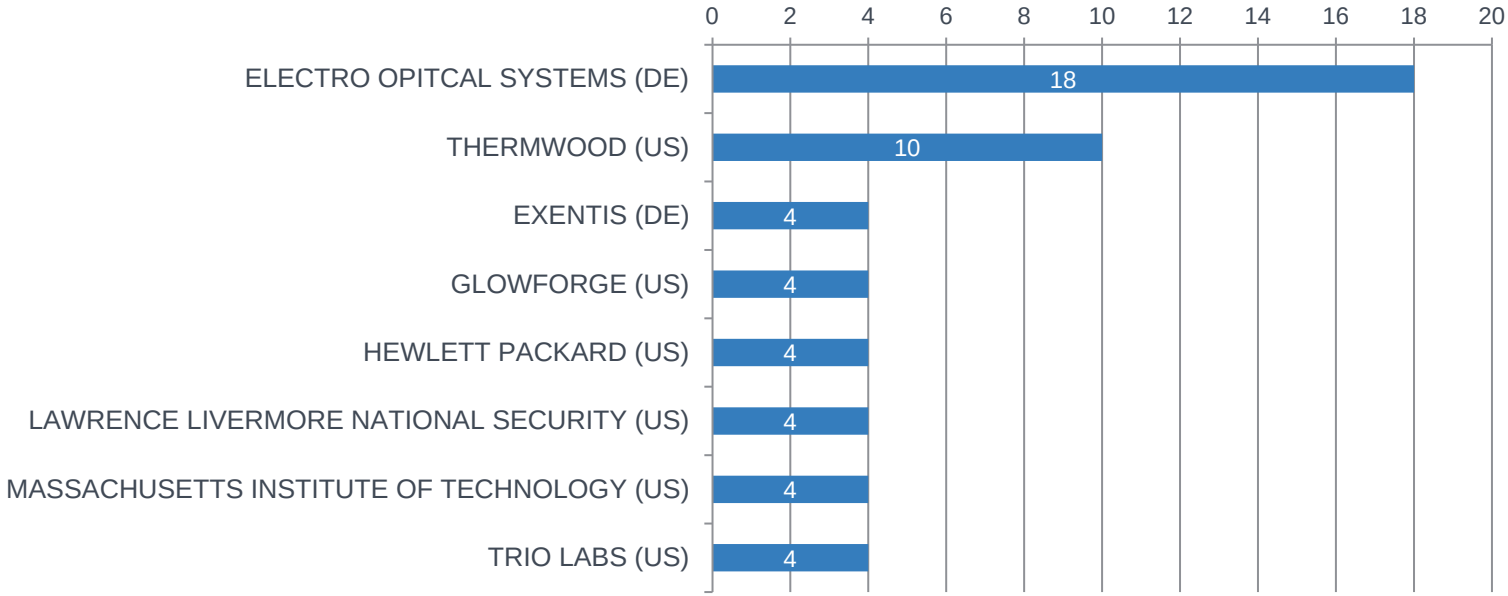
- **Overall high rate of pending patents in the applicants portfolio indicate a novel technology field with recent filings**
- **Chinese Universities very active in the field**



Patent family counting / Applicants with >4 patent families /legal status of all members of the family

Top players - EP/WO/US published patent applications

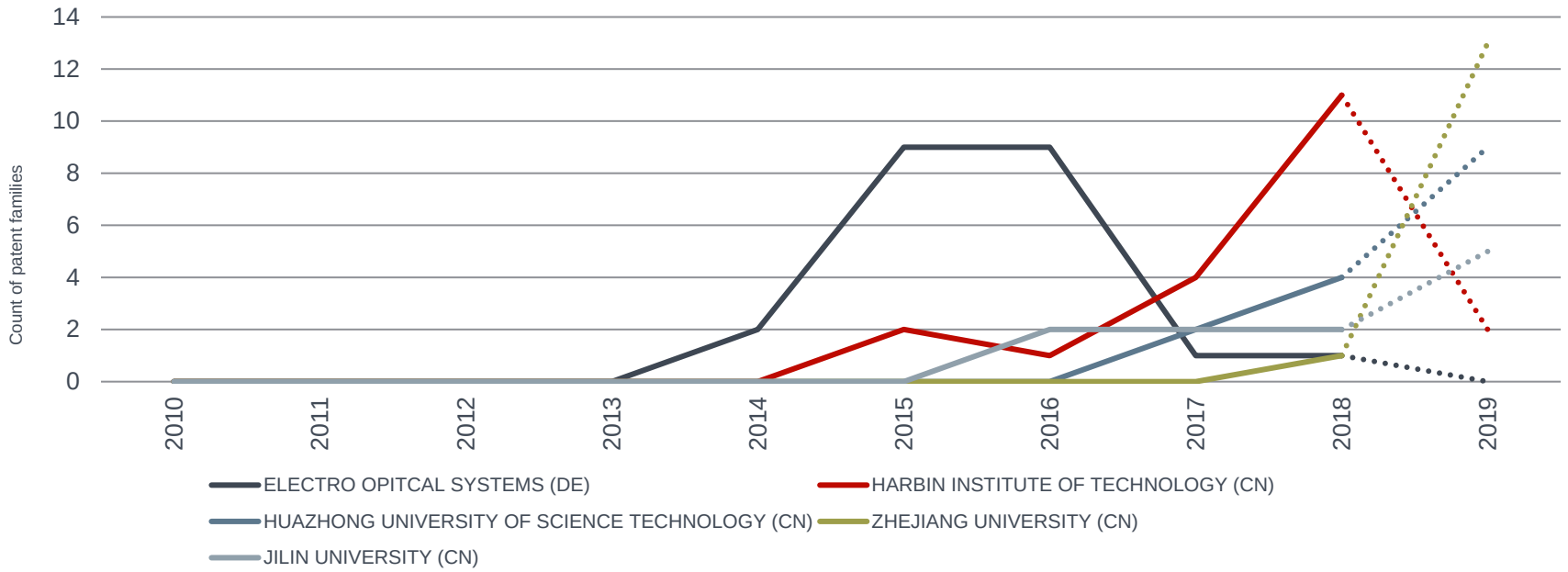
- **When analysing the top applicants with either a EP, WO or US published patent application, the Chinese players disappear (due to their domestic only filing behavior)**
- **Two companies specialised in additive manufacturing lead the ranking: the German Electro Optical Systems and the US company Thermwood.**



Patent family counting / Applicants with >4 patent families

Top players – Evolution of first filings (priority) worldwide

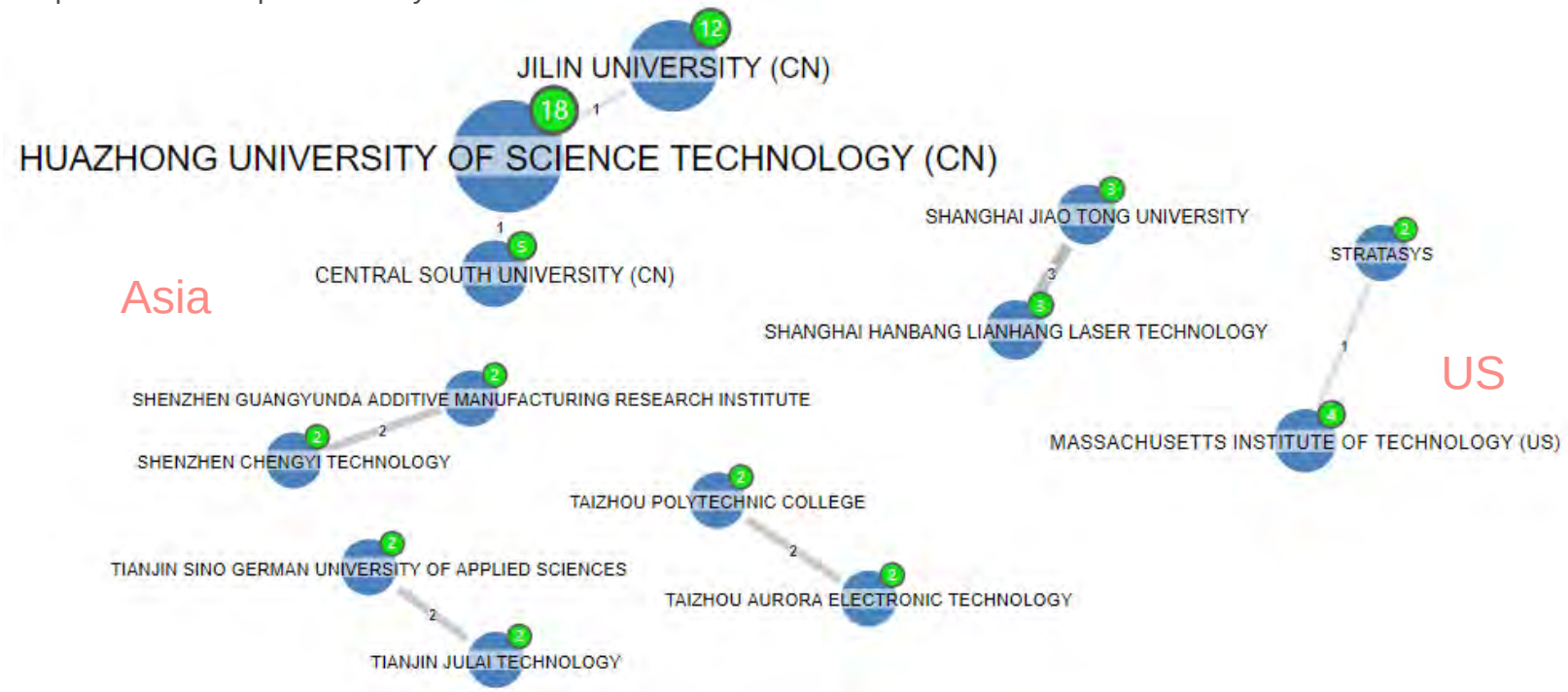
- German Electro Optical System (EOS) very innovative in 2015 and 2016
- Chinese Universities file especially in the last two years



Patent families by 1st priority year. Dotted lines: Patent data is incomplete for priority year 2019 due to 18 month period till patent is published.

Patent applicant co-authorship node maps

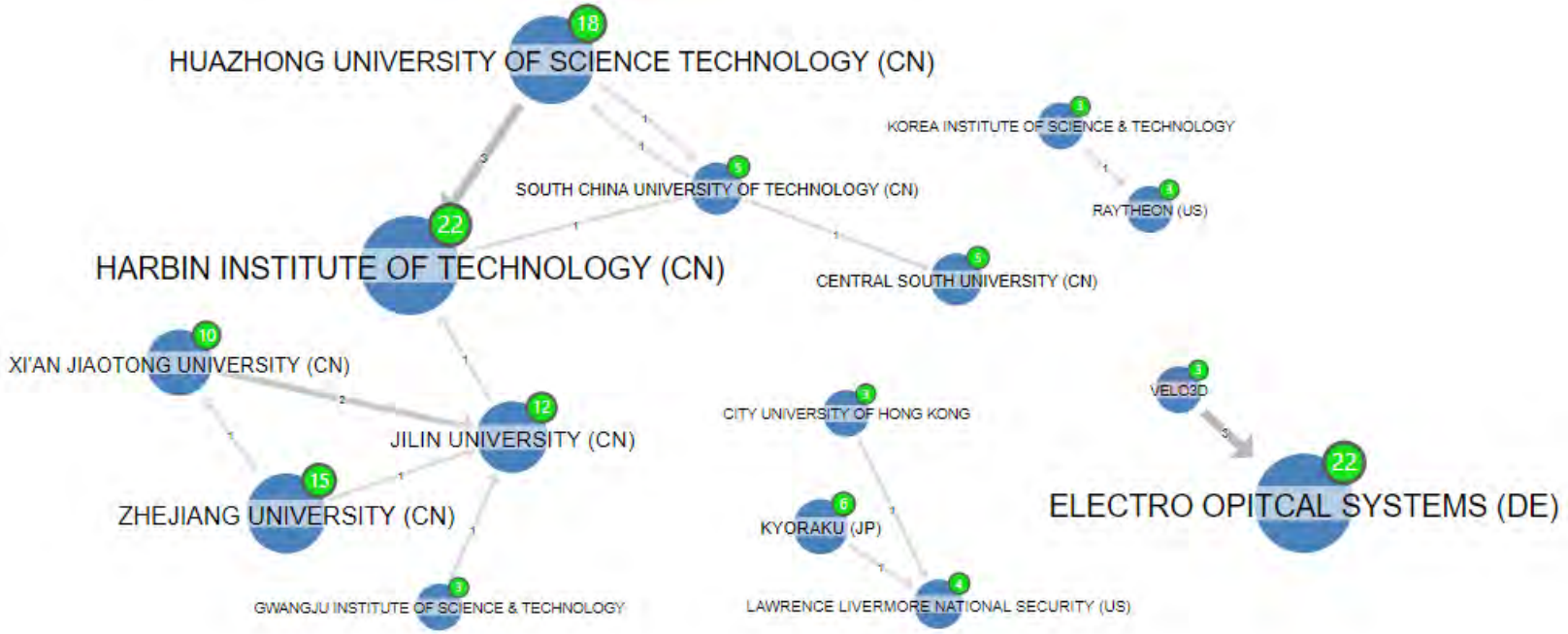
- Collaboration mainly between domestic (Chinese) research institutes only
- Only US collaboration is one co-authored patent family of the MIT and Stratasys, an American-Israeli manufacturer of 3D printers and 3D production systems



Patent family count, min. 1 patents per applicant and connection. The circle and font size is proportional to the total patent portfolio size of the applicant (families)
The line visualises the collaboration (via co-applicant or ownership change) and the number indicates how many patents are affected. Source: Orbit and own analysis.

4D Printing - Patent applicant citation node map

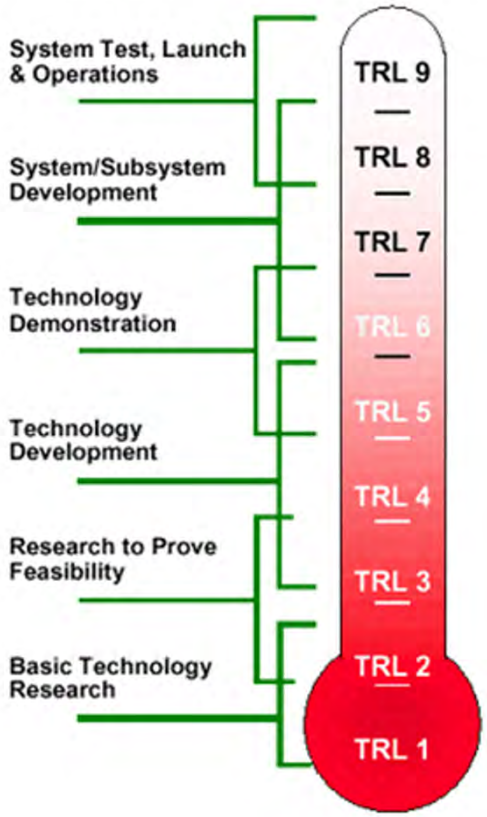
- This node map shows how patent families from a company patent portfolio are cited by others via applicant or examiner citations. This can help us to identify portfolios that have strong interactions with each other and influenced each other.
- In the 4D printing landscape we detect an influence cluster between the Chinese Universities, especially Harbin Institute of Technology that has received most citations from others.

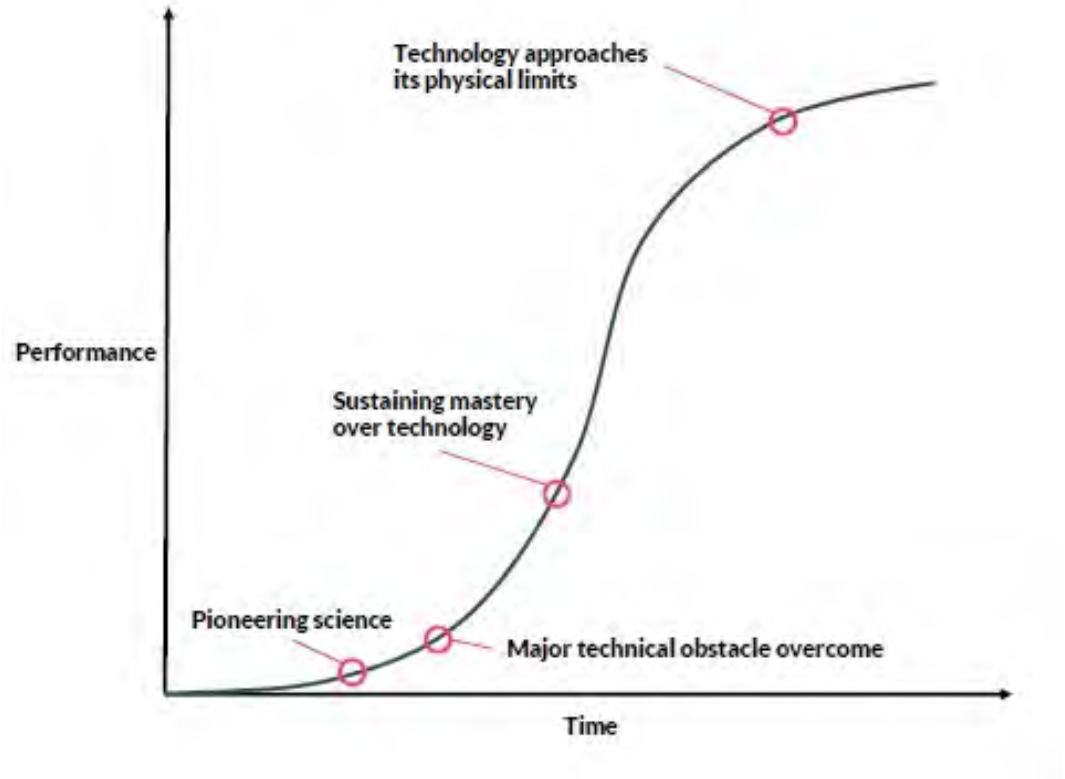


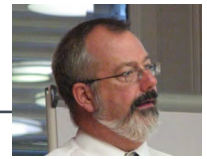
The circle size and the number represent the total patent portfolio of the applicant (families). The arrow visualises the citation direction and the number indicates how many patents cite the applicant where the arrow is directed at (examiner & applicant citations). Examiner and Applicant citation count, and citation grouping on family level (total number of times a patent family has been cited by other patent families) The map is shows nodes with min. 1 citations between applicants with a portfolio of min 3 patent families. Source: Orbit and own analysis

4D Printing technologies - Spatial concept map

This graph identifies the possible technology clusters protected in the 4D printing patent landscape.
A point corresponds to a patent family and the location is calculated according to the similarity between the different documents.


System Test, Launch & Operations
System/Subsystem Development
Technology Demonstration
Technology Development
Research to Prove Feasibility
Basic Technology Research
TRL 9
TRL 8
TRL 7
TRL 6
TRL 5
TRL 4
TRL 3
TRL 2
TRL 1


Technology approaches
its physical limits
Performance
Sustaining mastery
over technology
Pioneering science
Major technical obstacle overcome
Time



ANY QUESTIONS?

Follow-up

nclarke@epo.org

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