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Geometry of wood screws: a patent review

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Abstract
The article describes the results of the review and analyses of the patent literature relating to screws for wood materials used in the furniture manufacturing and in building construction. Based on the queries performed in several databases, 611 patent families containing 1031 unique patent documents from 1902 to 2017 have been identified. These documents were analyzed, and as a result, an overview was obtained containing screw inventions that are the most influential for the present state of the art of joinery. The number of forward citations and sizes of patent families were considered in the identification of the inventions recognized as the most influential. Additionally, the oldest often-cited screw patents were also quoted. As a result, eight very significant screw inventions were identified and the types of technical issues that these inventions solve were indicated. Additionally, these results were confronted with topics taken in scientific literature. This confrontation points to the weak link between scientific literature and patent literature in the field of threaded fastener for wood materials.

1 Introduction

Wood and wood-based materials are produced as a technologically treated wood (such as for example solid wood, glued wood and more reconstituted products—veneers and plywood, particleboards, fiberboards—also as mixtures of substances WPC etc.). These numerous kinds of porous and fibrous engineering materials are characterized by various construction features with lack of uniformity. This is a serious challenge in joinery (Sydor 2005, 2011; Sydor and Wieloch 2009; Branowski et al. 2018). One of the most popular ways of joining elements made of wood and wood-based materials is the use of single or multi-element mechanical fasteners, especially screws. A characteristic feature distinguishing a screw from a bolt is the fact that a bolt cooperates with a previously fabricated nut, while a screw forms an internal thread in the workpiece all by itself. Often, it also bores a pilot hole.

The screws intended for wood materials have several specific construction elements, such as a screw drive to temporally attach a screwing tool, a head that limits the screw-in depth and blocks the screw in the workpiece, non-threaded shank, threaded shank forming a thread in the wood and very often a tip boring a pilot hole (different screw tips boring a pilot hole are shown for example in Blaß and Siebert 1999 and Pirnbacher and Schickhofer 2007). An outer layer may also be an important construction feature of screws. Apart from its main decorative and protective function, it could decrease friction torque during screwing. Screws may also be equipped with other, less common construction elements. The functions of the main structural elements of the wood screws are presented in Table 1.

The screws can be loaded axially (by pulling or pushing force) or radially (by shear force), acting in one or in many shear planes (Eurocode 5: Design of Timber Structures: Part 1-1: General—Common Rules and Rules for Buildings 2004). During screwing and unscrewing, the torque temporarily loads the screws. The screws can be a part of a multi-element fastener (Fig. 1a) or be a single or grouped fastener in the construction (Fig. 1b). The screws may also be used to attach different kinds of hardware to the surface of elements (Fig. 1c).

The oldest description and technical drawing presenting the structure and use of screws as wood fastener dates back more than 460 years (Agricola 1950). The first screws were handcrafted by a smith, and due to the high production cost, they were not widespread in technology (in the furniture industry, carpentry, or mechanical engineering). Modern screws, that is to say mass-produced cheap fasteners made through plastic processing, were developed in the middle of the 19th century (Rybczynski 2000). Despite, the seemingly

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Table 1 Components of the wood screw (on the example of a screw produced by HECO-Schrauben)

Element of a structure	Picture	Main functions
Head		Attaching and detaching a screwing tool, transmission of the torque, limit of the screw-in depth (especially to hold the components together), and sometimes protection against unscrewing or milling the edge of the hole (protection against surface damage)
Unthreaded shank		Transmission of the axial forces, radial forces and torque; prolongation of the screw
Shank profile		Enlarging the diameter of the pilot hole, transmission of the axial forces, radial forces, and torque
Threaded shank		Thread burnishing in the workpiece, transmission of the axial forces, radial forces, and torque
Tip		Boring a pilot hole, initial cutting or burnishing of the thread

simple construction form of the screws, new constructions are still developed in response to the various technical requirements that they must face.

The important and breakthrough inventions are usually submitted to national or international patent offices that issue so-called patents. A patent is an administrative decision made by a country or an international organization that reserves to the patent's owner a time-limited exclusive right to reap the benefits from the technical solution described in the patent application (Sydor 2017). Every patentable invention must be novel, non-obvious and useful. There are basically three types of patents: industrial designs (design patents in USA), utility models and plant patents. In the case of threaded wood fasteners, we can speak of the first two types of patents.

The Civilization Techno-Economic Network of human activity consists of six correlated poles: science pole, transfer pole, technological pole, financial pole, development pole, market pole (Bell and Callon 1994). The patent literature is an element of the technological pole. According to the Altshuller's theory (TRIZ), all innovations emerge from the application of a very small number of inventive strategies and technology evolution trends are highly predictable (Altshuller and Shapiro 1956; Terninko et al. 1998; Mann 2001). Patent literature constitutes a reliable and very organized collection of valuable technical knowledge (Abbas et al. 2014), and it can provide valuable input for support of decision on research and development strategies (Yoon et al. 2013) in particular regarding the identification of the most important technical challenges. That is why it is valuable to identify and analyze the essential patents in each domain. The purpose of this article is to indicate the most important patented inventions regarding screws for all wood materials and to identify kinds of issues that the inventors of the most innovative screws were trying to solve. This article presumes that all valuable inventions are patented.

Fig. 1 Examples of wood screws usage: **a** screws in a post and beam construction (source: RICON 2017), **b** furniture screws (confirmat screws) (source: Howard 2016), **c** a cabinet hinge showing side-to-side adjustment screw (source: Dvortygirl 2007)

2 Method for wood threaded fasteners patents search

Patent documents were searched by means of several commonly available databases (Patent Lens, Google Patents, WIPO—Patentscope). In some cases, the information was searched directly on the patent office's websites (EPO—Esp@cenet, USPTO—Public PAIR, IPDL—Japanese Patent Office, SIPO—Chinese Patent Office, DPMA—German Patent and Trade Mark Office). For data analysis, a chosen "Software as a Service", which has a global patent coverage with full-text data, was used. In order to correctly identify patent documents relating to screws for wood materials a specific query was formulated. Patent documents containing the words "wood" and "screw" in "Title", "Abstract" or "Claim" ("TAC") fields and being classified at the same time in the International Patent Classification to the "F16B 25" classification group were searched. This group has the following structure (Section F. Mechanical Engineering; Lighting; Heating; Weapons; Blasting 2016):

- F16B 25/00 Screws that form threads in the body into which they are screwed, e.g. wood screws, self-tapping screws [2006.01]
- F16B 25/02 by a cutting and material removing action, e.g. fluted self-tapping screws [2006.01]
- F16B 25/04 by a slicing and material displacing action, e.g. wood screws with sharp thread crests [2006.01]
- F16B 25/06 by swaging, i.e. material deforming action [2006.01]
- F16B 25/08 by a combination of any two or all of the actions provided for in groups F16B 25/02-F16B 25/06 [2006.01]
- F16B 25/10 Screws performing an additional function to thread-forming, e.g. drill screws [2006.01]

All five above-mentioned subgroups of the "F16B 25" classification group were taken into account. All the screw inventions documented by patent applications since 1846 were taken into consideration; however, the inventions submitted to the national patent offices after 1902 have been analyzed more thoroughly. The inventions filed for patenting before 1902 were analyzed provided that modern patent documents refer to them.

3 Results and discussion

3.1 Number and structure of patent documents relating to wood screws

As a result of the query, 645 patent families containing 1157 patent documents from 1902 to 2016 have been initially identified. Subsequently, an overview and verification of the obtained pattern family list were carried out in order to remove from this list all patents that are not related to screws for wood based materials. Eventually, a collection was obtained consisting of 611 patent documents' families containing 1031 patent applications for the invention or decisions granting protection for the invention. The results of the described search are presented in Table 2.

As shown in Table 2, the classification group F16B 25 contains 5808 families of fastener inventions, among them threaded fasteners for wood-based materials constitute 9.5%. The collection of IP (Intellectual property) documents consisting of 1031 patent documents related to screw inventions for wood-based materials contains 34% of utility models and 66% of industrial designs.

The term of a patent starts with the application at the patent office, then the application is published with the given priority date. After a few years, the applications with an appropriate level of inventiveness receive legal protection, and in the end (depending on the period that has been paid), this protection lapses. For each patented invention, five dates delimit this process: filed, priority, published, grant, expiry. The described sequence of dates in relation to the number of wood screw patents after 1902 is presented in Fig. 2.

As shown in Fig. 2, a significant increase in the number of patent applications took place at the beginning of the 1990s and the maximum falls in the years 2000–2011 when the number of published patent applications increased from 16 up to 40 per year.

It is possible to point out several leading countries in the volume of submitted inventions. The greatest number of inventions comes from Japan, thereafter from China and Germany. In these three countries, about 60% of all

Table 2 Results of the search for threaded fasteners for wood materials patents

Criteria	Number of all patent families in F16B 25 group	Number of all patent documents in F16B 25 group	Number of wood screw patent families in F16B 25 group	Number of wood screw patent documents in F16B 25 group
Applications and granted patents (1902–2017)	5808	13545	611	1031
Granted patents (1902–2017)	2916	6727	337	625

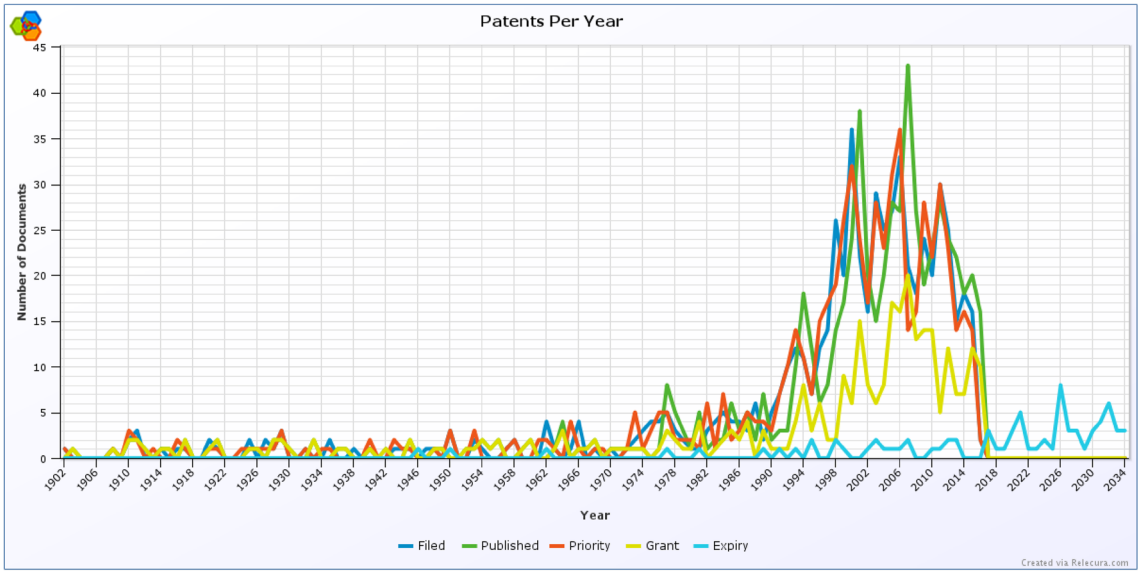

Fig. 2 Number of patents per year

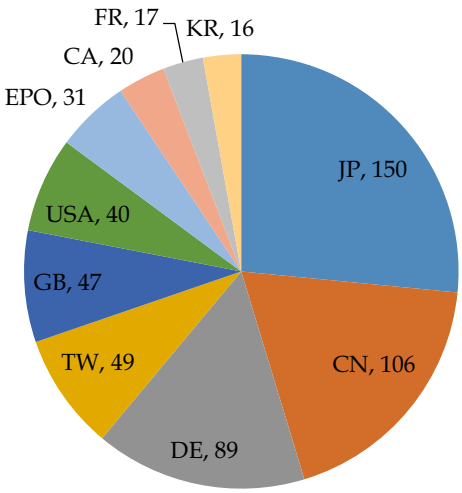

Fig. 3 Screw inventions per country (JP—Japan, CN—China, DE—Germany, TW—Taiwan, GB—Great Britain, USA—USPTO, EPO—European Patent Office, CA—Canada, FR—France, KR—Republic of Korea)

screw inventions intended for wood-based materials were filed for patenting for the first time (Fig. 3).

Number of screw patents listed in Fig. 3, in particular countries with a breakdown by year, is presented in Fig. 4.

Figure 5 reveals the share of the USA remains at a relatively stable level, decreasing share of Japan and Germany as well as increasing share of China in the number of inventions filed for patenting.

3.2 Influence of patents on other patents and non-patent literature

Pattern quality is usually determined by the following parameters: forward citations (citations received from subsequent patents), backward citations in the patent application, the number of claims and family size (Lanjouw and Schankerman 2004). The number of forward citations allows the measurement of: (1) the economic value of the invention, (2) the invention's impact on the development of other inventions (Gay and Le Bas 2005). An overview of the most-cited wood screw patents in other patent documents is presented in Fig. 5. It summarizes the 11 most-cited patent documents with several forward citations for each patent. The most-cited patent is mentioned in 87 other patent documents; at the same time, it is a patent with the highest annual number of citations.

The number of forward citations is correlated with the term of a patent; that is why, apart from the number of forward citations, Fig. 5 also contains the annual citation frequency of the most-cited patent documents. Two documents particularly stand out in this field: the US 5516248 A from 1996 cited 4.4 times per year and the US 6056491 A from 2000 cited 4.2 times per year.

Patents of economically beneficial inventions are extended for subsequent years despite the progressively increasing fee charged by the patent office each year. This correlation was confirmed by Harhoff and his team on the basis of the analyses carried out in the USA and Germany (Harhoff et al. 1999). They stated that the most-cited patents are covered at the same time by the maximal 20-year

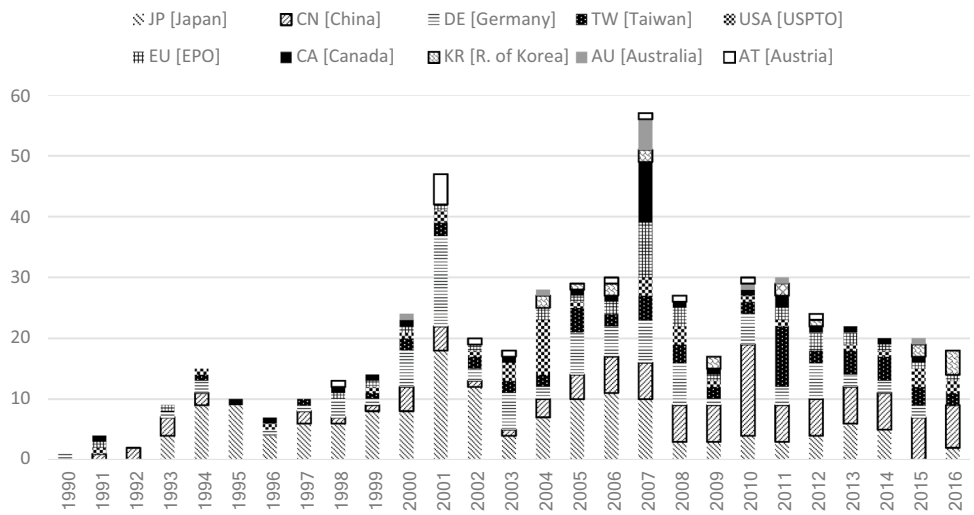

Fig. 4 Top countries by published year

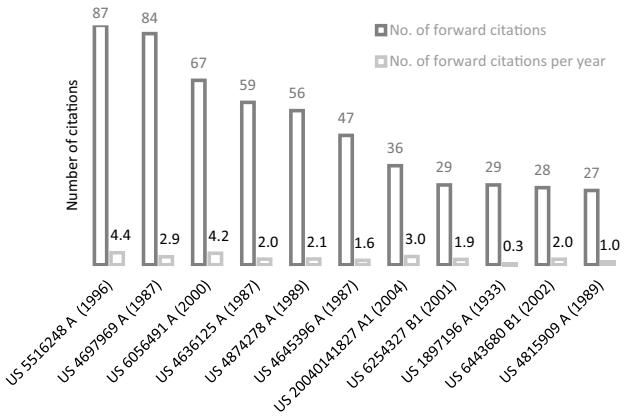

Fig. 5 An overview of the most-cited wood screws patents in other patent documents (the number of forward citations indicated for each patent) (DeHaitre 1996; Sparkes 1987; Hsu 2000; Burgard 1987; Kawashita 1989; McCauley et al. 1987; Dicke 2006b; Chen 2001; Hunt 1933; Bodin 2002; Simons 1989) (according to lens.org, 2017.07.10)

protection period. The oldest ten wood screw patents with still ongoing protection are presented in Table 3.

It is also possible to indicate the new patents for which the fee was paid many years in advance. They are also the solutions recognized as economically advantageous at the patent-pending stage. Table 4 contains such a summary.

Wood screws patents documents could also be analyzed in terms of number of citations that appear within them. The more citations there are, the wider is the description of the state of the art related to the invention filed for patenting. It has been stated that among the 611 identified patent documents, 582 patents quote other patents, while 43 patents quote from 11 to 20 other patents and only 26 patents quote over 20 other patents.

Only 32 patent documents cite non-patent literature (scholarly published work). Five patents with the biggest number of references are listed in Table 5.

No references in the scientific publications to the patents of screw for wood materials were found. One of the few exceptions is the scientific monography by Ulrich Hübner, which cites about 20 patent documents of wood screws (Hübner 2014) Potential reason for this may be the language of patent documents, which is different to the language of the scientific community and therefore, the relation of gaining the new knowledge to time consuming study is not satisfying.

3.3 The most influential inventions relating to geometry of wood screws

Some of the hundreds of identified patents are characterized by specific bibliometric features. They are presented in Table 6.

The most-cited modern patents are the descriptions of inventions tackling an important technical issue. The fact that patents cite some other patent document means that creators of more recent patent solutions declare in their patent applications that they found a better solution than the quoted patent. This implies that patents that are cited very often have very huge impact on the development of technology, but that the strength and statistical significance of this relationship varies across geographical regions and across channels of knowledge diffusion (Duguet and MacGarvie 2005). The biggest patent family contains a solution that is very interesting in terms of utility and merits being reserved over as large an area as possible (in many patent offices). The patent applications filed in subsequent patent offices entail the payment of the next fees; that is why only those patent solutions that were recognized as economically advantageous are filed in many patent offices (it is worth noting that limited patent DE 202004002877 U1 and

Table 3 The oldest ten patents of wood screws with still ongoing protection

Patent or patent application #	Number of family members	Title	Priority year	Estimated expiry year
EP 0831239B1 (Schulte 1998)	18	Cutting screw	1996	2017
NZ 328831 A [US 6109850 A (Commins 2000)]	6	Screw fastener in metal connector to wood structure shear connection	1996	2017
DE 29621923 U1 (Wieland 1998) [EP0849474A1 (Wieland and Litze 1998)]	9	Drill screw	1996	2017
EP 0970312B1 (Petit 2000)	8	Novel wood screw with cut-out thread	1997	2018
US 6152666A (Walther et al. 2000)	14	Screw for use as a fastener in fibrous material such as wood	1998	2018
EP0984177B1 (Wieland 2000)	5	Connecting screw for wood-concrete composite structure	1998	2019
AU 2000/012778 A (Ulryck 2001) (FR 2786229 B1)	4	Wood-screw or the like	1998	2019
CA 2299129 C (Lindal 2008)	4	Waterproof joints between timbers	1999	2020
US6056491A (Hsu 2000)	1	Screw having cutting teeth formed on threads thereof	1999	2019
AU 760715 B2 (Saman and Gurong 2003)	2	Improvements relating to self-drilling screws	1999	2020

Table 4 The longest protected patents of wood screws

Publication #	Title	Priority year	Expiry year
US 20160146241 A1 (Eckert and Wunderlich 2016)	Wood screw with intermediate thread sections tapering to the front	2013	2034
EP 2811182 A1 (Humm et al. 2014)	Screw for drilling and tapping in a first supporting surface section and a harder second supporting surface section	2013	2034
US 20160115989 A1 (Hubmann 2014, Patent application)	Screw	2013	2034
US 20150308481 A1 (Dissing 2015)	Method and screw for mounting fiber cement planks	2012	2033
US 9145911 B2 (Shih 2015)	Anti-split wood screw	2013	2033
US 8998550 B2 (Platt 2015)	Hardware attachment system	2013	2033
EP 2669879 A2 (Rössner 2013)	Safety system for construction of a structure with a wooden component and structure produced using such a safety system	2012	2033
US 8905696 B2 (Lapointe 2014)	Extension fastener for portable tool	2012	2033
EP 2633959 B1 (Simon and Simon 2013)	Device for securing the wooden handle in the eye of a hammer head and screw for attaching a wooden handle in the eye of a hammer head	2012	2033
US 9377045 B2 (Su and Su 2016)	Wood screw	2012	2032

limited patent DE 29906200 U1 were proposed by the same inventor and are representatives of two large patent families). Patents that cite many other patents are patents that describe the state of the art very widely. It may be expected that a design problem has been identified within them, an entire sequence of proposed solutions from the older patent documents has been quoted and in the end, one's own solution to respond to this problem has been presented. The oldest presently cited screw patents contain solutions for fundamental issues. These issues are still relevant today, which was reflected by the fact that, despite the passage of time, they are still quoted in the new patents. The most cited patent in modern patent applications is the US 126366 A from 1872 that was quoted in 165 patent documents. This patent describes a solution that significantly decreases resistance encountered while driving a screw.

4 Conclusion

In global patent literature, it is possible to identify over 600 patent documents related to screws for wood-based materials. After analysing these patents, it can be stated that:

Table 5 Number of non-patent literature cited in patents

Patent no., filed, reference	No. of cited non-patent literature
US 7832173 B2 (2000) (Crawford et al. 2010)	18
US 9482258 B2 (2012) (Park 2016)	16
US 7189045 B2 (2004) (Mcgovern and Druschel 2008)	10
US 7367768 B2 (2007) (Mcgovern and Druschel 2007)	10
US 9051726 B2 (2013) (Vandenberg 2014)	6

Patents US 7189045 B2 and US 7367768 B2 are in the same patents family

1. In the recent hundred years a significant increase in the number of patent applications took place at the beginning of the 1990s and the maximum falls in the years 2000–2011. There are several leading countries in the number of submitted inventions of screws for wood materials. The greatest number of inventions comes from Japan, thereafter from China and Germany. Over recent years, the share of Japan and Germany decreases; the share of China increases in the number of inventions filed for patenting for the first time.
2. By filtering patents by two very important indicators, the number of forward citations and the size of patent families, it can be observed that there are only a few significant patent documents for other patent applications, 13 of them are listed in Table 5.
3. Patents have very poor interactions with non-patent literature. Patents are very little cited in non-patent literature, especially not cited in scientific literature. Only 32 patent documents cite non-patent literature.

The most important patents tackle the following issues: reduction of the friction encountered while driving a screw (DeHaitre 1996; Hughes 2017), reduction of the risk of wood cracking while driving a screw (Shih 2015), improvement of the self-drilling of the pilot hole (Sparkes 1987; Humm et al. 2014), improvement of the thread forming in a workpiece, protection against unscrewing (Taneichi 2013) and improvement of the installation of the screws. These issues may be considered the most important technical challenges in construction of the screws for wood-based materials. Patents of screws recognized as the most influential are presented in Table 7. This table shows the most crucial screw patents and contains information concerning a type of issue that was solved by each of these patents, therefore it constitutes a synthetic summary of the patent document analysis results described in this article.

The problems of the crucial patents shown in Table 6 do not quite correspond with the topics of published research papers concerning screws for wood-based materials. A major concern for the scientists is the screws' pull-out resistance (Eckelman 1988; Rajak and Eckelman 1993; Erdil et al. 2002; Özçifçi 2009; Hübner et al. 2010; Kariz et al. 2013; Sydor et al. 2015; Sydor and Wołpiuk 2016a, b; Gaunt 1997; Ayyildiz and Malkocoglu 2001; Aytekin 2008; Gates 2009; Wołpiuk and Pohl 2009; Pohl and Wołpiuk 2011; Tankut 2011; Hübner 2014; Kasal et al. 2014; Semple et al. 2014; Taşçioğlu et al. 2014; Gašparík et al. 2015; Wołpiuk and Sydor 2016; Ringhofer 2017). This property is usually analyzed from the point of view of changing constructive properties of wooden workpieces, (Eckelman 1988; Rajak and Eckelman 1993; Erdil et al. 2002; Hübner et al. 2010; Kariz et al. 2013; Sydor and Wołpiuk 2016a; Ayyildiz and Malkocoglu 2001; Aytekin 2008; Gates 2009; Wołpiuk and Pohl 2009; Pohl and Wołpiuk 2011; Tankut 2011; Kasal et al. 2014; Semple et al. 2014; Taşçioğlu et al. 2014; Gašparík et al. 2015; Wołpiuk and Sydor 2016), less often from the point of view of the screws' shapes (e.g. influence of the tip on the screw features: Gahagan and Newlin 1938;

Table 6 Summary of the wood screw patents analysis results

Feature	Patent and application numbers, dates and bibliographic references	Substantiation
No. of forward citations	US 5516248A (1996) (DeHaitre 1996) US 4697969A (1987) (Sparkes 1987) US 6056491A (2000) (Hsu 2000)	Cited 87 times (by other patents) Cited 84 times (by other patents) Cited 67 times (by other patents)
The largest families of patents and patent applications	IL 46025 D0 (Rosan and Reece 2018) CA 2827504A1 (Vandenberg 2014) DE 29906200 U1 (Dicke 1999) DE 202004002877 U1 (Dicke 2006a)	29 members (1975–1981) 24 members (2011–2015) 22 members (1999–2009) 21 members (2005–2011)
No. of backwards citations	US 9482258 B2 (2016) (Park 2016) US 9051726 B2 (2005) (Vandenberg 2014) US 8480343B2 (1013) (Vandenberg 2014)	Cites 176 patents Cites 155 patents Cites 148 patents
The oldest patents cited by contemporary patents	US 4704 A (1846) US 24393 A (1859) US 126366 A (1872) (Wills 1872)	Cited by 4 patents (1952–2008) Cited by 5 patents (1972–2009) Cited by 165 patents (1952–2014)

Table 7 The most influential inventions relating to geometry of wood screws

Bibliographic data	Substantiation	Essence of the invention
US 5516248 (1996) (DeHaitre 1996)	Cited 87 times (4.4 times per year)	Reducing the friction between the screw shank and the workpiece
US 4697969 (1987) (Sparkes 1987)	Cited 84 times (2.9 times per year)	Improved self-drilling
US 6056491 (2000) (Hsu 2000)	Cited 67 times (4.2 times per year)	Prevent the wood from being cracked
US 126366 (1872) (Wills 1872)	Cited 165 times (1.1 times per year)	Boring a pilot hole Reducing the friction Prevent the wood from being cracked
IL 46025 D0 (1975) (Rosan and Reece 2018)	Patent family with 29 members	Improved self-drilling
CA 2725335 A1 (2010) (Vandenberg 2014)	Patent family with 24 members	Improved wood screw and improved its installation method
DE 29906200 U1 (1999) (Dicke 1999)	Patent family with 22 members	Protection against unscrewing
DE 202004002877 U1 (2004) (Dicke 2006a)	Patent family with 21 members	Improved thread forming in workpiece

Pirnbacher et al. 2009)). This points to the very small correlation between the two important areas of human activity in threaded fasteners for wood materials: science pole and technological pole described by patent documents (in the sense of techno-economic networks described by Bell and Callon 1994).

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