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3D printing in wood industry - an overview of recent developments

Druk 3D w przemyśle drzewnym - przegląd aktualnych badań

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Abstract

Systematic review of literature regarding directions of development of 3D printing in wood industry has been performed. Two main areas of development were designated - 3D printing applications in both wood construction and furniture as well as new technologies. Issues discussed in the literature during the last 10 years were presented, including possibilities and difficulties attempted to resolve. Furthermore, topics consistent between authors, such as optimisation, cost reduction and mitigation of negative impact on environment has been discussed. It was indicated that, despite difficulties with implementation, 3D printing in wood industry might be an indispensable tool, in terms of both prototyping and production.

Streszczenie

Przeprowadzono systematyczny przegląd literatury dotyczącej kierunków rozwoju druku 3D w przemyśle drzewnym. Wyodrębniono 2 główne nurty tego rozwoju, tj. zastosowania druku 3D w budownictwie drewnianym i meblarstwie oraz nowe technologie. Przedstawiono problematykę poruszaną w literaturze na przestrzeni ostatnich 10 lat z uwzględnieniem możliwości, problemów które próbowano rozwiązać oraz tematów wspólnych dla większości autorów, takich jak optymalizacja, ograniczenie kosztów oraz zmniejszenie negatywnego wpływu na środowisko. Wskazano, że pomimo trudności z wdrożeniem druk 3D w przemyśle drzewnym może być niezastąpionym narzędziem, zarówno projektowym jak i produkcyjnym.

Keywords: 3D printing, wood industry, furniture

Słowa kluczowe: druk 3D, przemysł drzewny, meblarstwo

Introduction

3D printing, also known as additive manufacturing, is a collection of technologies based on laying material layer upon layer, until a final shape of manufactured piece is achieved. Compared to traditional, subtractive manufacturing, 3D printing offers a significant reduction of waste and residues, as well a big improvement in production flexibility. Unit cost of additive manufactured elements is not dependent on complexity of its shape or production scale, while each element may be individually modified (Siddique et al., 2019). There are 7 technologies of 3D printing currently in wide use, such as Direct Ink Writing (DIW), Liquid Deposition Molding (LDM), Stereolithography (SLA)/Digital Light Processing (DLP), Selective Laser Sintering (SLS)/Selective Laser Melting (SLM), Laminated Object Manufacturing (LOM), Three-Dimensional Printing (3DP)/Polyjet, and the most popular, Fused Deposition Modelling (FDM), also known as Fused Filament Fabrication (FFF) (Li et al., 2023). In FDM technology a thermoplastic material, usually in a form of filament, is melted in a nozzle travelling in 3 dimensions. The molten material is laid layer by layer until a final shape is achieved (Fig. 1).

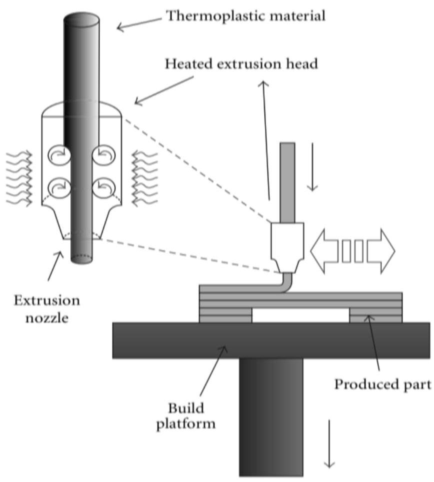

Fig. 1. FDM printing process (Tsouknidas 2011)
Rys. 1. Proces druku w technologii FDM (Tsouknidas 2011)

This technology, due to low cost, simplicity, and ease of use may be found in hobby, semi-professional (f.e. design bureaus, research and development centres) and professional settings (Stříteský 2020). Possibilities and relatively small limitations of this and other technologies cause 3D printing to be indispensable in rapid prototyping, but also widely used in education, medicine and industries such as car manufacturing or construction (Siemiński and Budzik 2015).

Historically, additive manufacturing may also be found in the wood industry, in the form of laminated materials, which are produced by gluing layers of veneer or lumber. However, in recent years, deployment of modern 3D printing technologies in wood industry has become increasingly popular. The goal of this article is to present the contemporary directions of development in this field.

Materials and methods

Web of Science (Clarivate) database was searched using following key phrases and their combinations: Wood technology; Wood industry; Furniture; Additive Manufacturing; 3D printing; Fused Deposition Modelling/Fused Filament Fabrication. The search results were filtered by date of publication as to include only articles published in the last 10 years (date of publication since 2013). Articles were then chosen based on their titles and abstracts. Duplicates and unavailable publications were removed. Remaining publications were sorted into two sub-categories, as seen below. Bibliographies of review articles were also analyzed and chosen using the process described above.

Results and discussion

3D printing applications

Grujovic et al. (2016) analysed cost effectiveness of 3D printing utilisation in the wood industry, emphasizing that additive manufacturing is indispensable in prototyping due to not only it's possibilities, but also a significant reduction of costs while compared to traditional techniques. However, authors point out that this reduction is not universal and, above a certain production scale traditional technologies offer lower costs per unit. Jarza et al. (2023) also indicate that despite difficulties combining additive and traditional, subtractive technologies, 3D printing allows production using single machining operations, unconventional, less restricted design and use of ecological, potentially recyclable materials. Svoboda et al. (2019) describe possibilities of weight reduction of 3D printed elements while preserving mechanical strength by optimising their structure. They also outline nearly limitless possibilities of designing the geometry of products manufactured in this technology. Authors present examples of furniture joints manufactured solely by 3D printing. This topic is present in many of analysed publications. Tauber et al. (2019) detailed 3D printed lightweight and reusable joints used in cloth hangers, concluding that, after optimisation of the production process, the joints' mechanical properties are suitable for this use. Song et al. (2017) present a computer-aided optimisation process of modular and fully reconfigurable furniture produced by 3D printing, laser cutting and traditional woodworking techniques. Smardzewski et al. (2016) describe additively manufactured, toolless and invisible joints for box furniture made out of fibreboards and particleboards. Similar, additively manufactured joints were also developed for frame furniture (Podskarbi and Smardzewski 2019). Nicolau et al. (2023) and Nicolau et al. (2022) describe utilisation of respectively SLS (Selective Laser Sintering) and FDM 3D printing to manufacture structural parts of chairs, outlining the possibilities of such applications, comparison to traditional mortise and tenon joinery and production optimisation process. Haeusler et al. (2017) present a computer aided geometry optimisation process for 3D printed frame furniture (Fig. 2) indicating cost effectiveness and relative simplicity of this technology. Ntintakis et al. (2019) demonstrate production and optimisation process of 3D printed chairs and tables made out of gypsum. Authors emphasize usefulness of additive manufacturing in rapid prototyping and possibilities of creating multi-colour pieces.

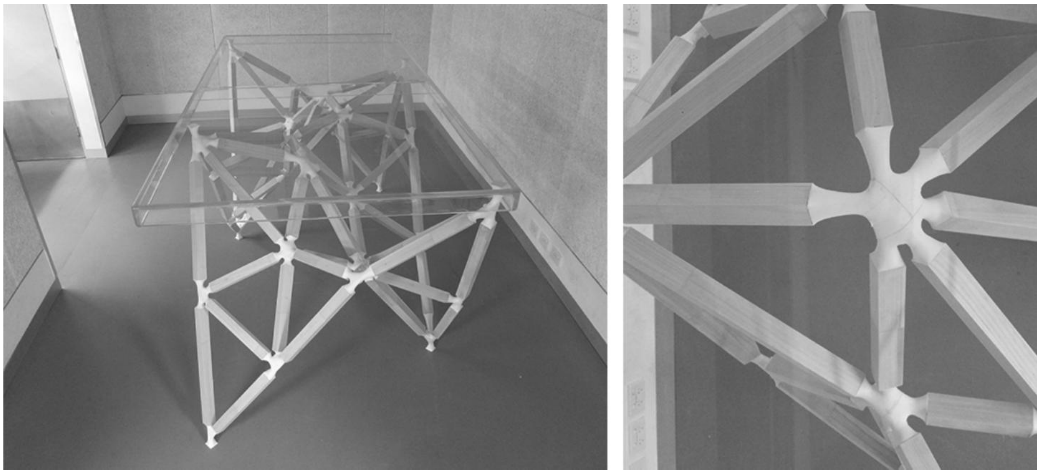

Fig. 2. Table manufactured using 3D printed joints (left) and 3D printed furniture joint (right) (Haeusler et al., 2017)
Rys. 2. Stół wykonany z użyciem łączników drukowanych 3D (po lewej) i łącznik meblowy drukowany w 3D (po prawej) (Haeusler et al., 2017)

Wood construction constitutes a second, besides furniture, large group of 3D printing applications described in analysed publications with the main focus on the subject of insulation. Bahar et al. (2023) analysed insulation properties of wood-polylactic acid 3D printed biocomposite. Authors outline the possibility of manipulating the heat transfer coefficient in a large range by changing geometry and printing parameters, however pointing out that the results are 38% to 57% worse than results obtained for traditional insulation materials such as glass wool or synthetic foams. Sekar et al. (2023) compared properties of wood-polymer biocomposite acoustic insulation panels created by pressing and 3D printing. Printed panels were characterised by higher, although narrower acoustic peak than the pressed panels while being less water resistant, which in turn suggest higher potential for biodegradation. Properties of similar insulation panels, also made from wood-polymer biocomposites were tested by Sekar et al. (2024). Authors show the possibility of tuning the acoustic insulation panels to dampen specific frequencies by modifying parameters of the production process. Besides insulation, applications of 3D printing in wood construction may also be found in researched by Smardzewski and Wojciechowski (2019) sandwich beams, created by laminating 3D printed lattice core with HDF boards. Authors describe mechanisms of breakage of such beams after exceeding their strength as well as concluding that mechanical properties of these beams depend on relative density of the lattice core.

New Technologies

Materials used in 3D printing have undergone a lot of development since the beginnings of these technologies. At the moment there are multiple different materials dedicated to specific applications and 3D printing technologies, such as thermoplastic polyurethane (TPU) and Alumide (Saad 2016). It is important to underline the ongoing research and development of new material formulations. Carne et al. (2023) analysed possibilities of 3D printing using a mix of fibrous mass with water glass in close to 1:1 proportions. Authors described mechanical properties of elements printed in this technology as comparable to 3D printed polylilactic acid, cement or wood-polymer composites. Similar technology, based on extrusion of beech fibrous mass mixed with water and starch has been reported by Gardan et al. (2016). Authors describe micro- and macroscopic structure of components manufactured in this technology, although pointing out fragility of the material and the need of further research and optimisation. Henke and Treml (2013) compared different adhesives meant for additive manufacturing technology based on particles identical to those used in particleboard production. Results of this analysis show possibility of constructing each layer and stacking layer upon layer out of this material by using gypsum and cement based adhesives. Similar technology, although utilising pMDI resin is described by Buschmann et al. (2021). According to authors, products of this technology are characterised by mechanical properties comparable to traditional particleboards and, while using lower layer thicknesses (7 mm), high geometrical accuracy. Kromoser et al. (2022) describes technique similar to two aforementioned technologies, based on mixing wood particles with adhesive and extracting this mix layer by layer. Authors focused highly on using only renewable resources and recycling potential of researched materials. Due to this a mix of lignosulfonates and starch was used as adhesive. Markstedt et al. (2019) developed 3D printing technology based on extrusion of cellulose nanofibers mixed with xylan, describing bonding mechanisms as similar to those occurring naturally during a tree's growth, while geometric structure imitating internal tree structure is accomplished by specially optimised printing process. Tao et al. (2021) present a technology based on plywood in which layers of veneer are laser cut and glued together. Authors emphasise, that processes used in this technology are currently broadly utilised in wood industry, which in turn should render it's adoption relatively cheap and easy. It is also outlined, that this technology allows for production of vast size, nearly unrestricted geometry and properties similar to those of plywood. Eversmann et al. (2022) describe 3D printing technology consisting of joining thin strips of willow wood into continuous ribbon, which is then laid layer by layer and bonded by photocurable resins (Fig. 3). Products printed in this technology may be used as a replacement of large-size construction wood while using fast growing wood species, usually not suitable for this use case. Authors also claim that this technology offers products more visually similar to natural wood than most new or currently used 3D printing technologies.

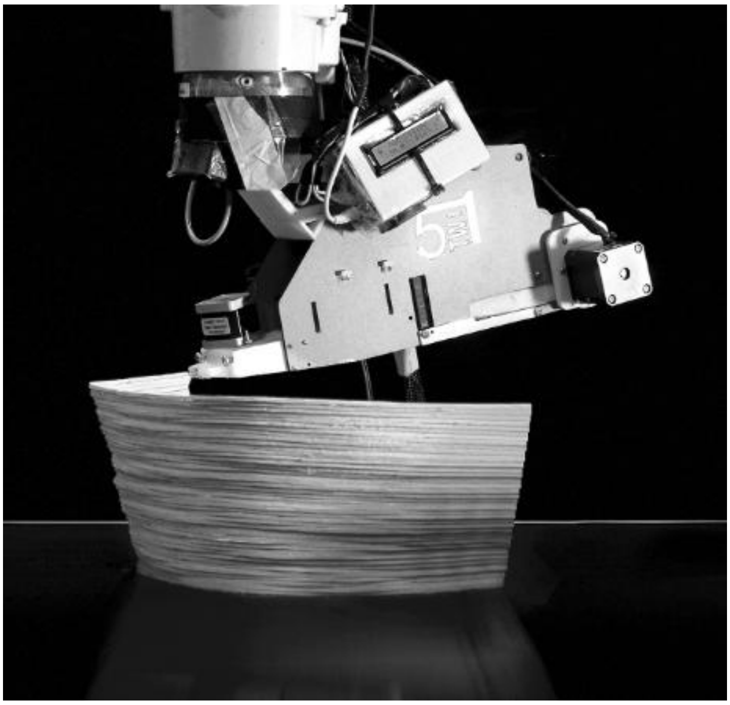

Fig. 3. 3D printing using continuous willow ribbon (Eversmann et al., 2022)
Rys. 3. Druk 3D za pomocą ciągłego włókna wierzbowego (Eversmann et al., 2022)

Conclusions

Analysis of available publications outlines two main directions of 3D printing development in wood industry - Applications in both furniture and wood construction as well as new technologies. Main focus of publications regarding 3D printing applications are furniture joints and insulation materials. Most authors indicate that 3D printing allows fast, optimal and low-cost design and prototyping. In the context of new technologies authors predominantly describe attempts to adapt contemporary lignocelulosic materials, such as fibreboards, particleboards and plywood for use in additive manufacturing. One, significantly different and noteworthy technology is based on printing with continuous willow wood ribbon. Authors seem to agree, that 3D printing presents problems with large component production and overall adoption in wood industry, which however during cited and future research may be resolved. Deserving of emphasis is nearly universal between authors use of biocomposites and other renewable resources.

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