

The Interaction of Design, Material and Production Methods in 3D Printing Technologies: An Analysis of Furniture and Interior Design Elements

Tuba ARKAN DEMİRÖRS

KTO Karatay University

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Introduction

Throughout the historical process, modes of production have shown a continuous change in line with technological advancements and economic transformations. While early trade methods transitioned into the mass production that became widespread during the Industrial Revolution, the digital age has now led to a preference for a personalized, low-volume production model. With the acceleration of information and digitalization in the 21st century, consumers have shifted towards unique, personalized, and specialized products rather than standardized and uniform products. This transformation has enabled users to design and produce their own products; in the field of furniture design, it has become possible for individuals to produce their own furniture with the “Do It Yourself (DIY)” approach (Kang, 2015). In this context, the DIY approach has significantly contributed to the adoption and proliferation of 3D printing technologies (Aydın, 2015). Over time, the expiration of 3D printer patents accelerated the use of 3D printers and brought the concept of “fast furniture” to the fore by encouraging low-volume but high-variety production. Thus, attempts to combine 3D printing with the design of furniture and interior elements have begun (Kang, 2015).

3D printer technology stands out as an innovative production method that expands the possibilities for unique and custom design in interiors. Thanks to its ability to produce without being tied to molds, it offers the potential to transform spaces into personalized works of art by challenging designers’ imagination. Furthermore, it provides unique solutions in furniture and interior designs by enabling the rapid production of designs that are suitable for user demands (Yıldıztepe & Arabacıoğlu, 2024). In addition, this technology not only provides aesthetics and functionality but also increases efficiency in design processes (Akbaba & Akbulut, 2021).

Interior architects and designers can produce prototypes of furniture and interior design elements using 3D printing technology in both their education and professional practice; thus, they find opportunities to test their designs in a versatile manner. The three-

dimensional models created with computer-aided software are converted into physical outputs using additional digital programs. Since this method is based on a layer-by-layer process, it is referred to as “additive manufacturing (layered manufacturing)” or “rapid prototyping” (Eke, 2019; Yang & Du, 2022). This rapidly developing technology makes the production, repair, or transformation of products possible in different spaces. It also allows a product design to be downloaded from the digital environment, copied, modified, or personalized before being printed. Furthermore, existing objects can be 3D-scanned and reproduced, which brings about a radical transformation in production processes (Saad, 2016).

As a result of the literature review conducted within the scope of this study, it has been observed that existing research on 3D printing technology has largely focused on general design fields, while remaining limited specifically to furniture design and interior design elements. Therefore, this study aims to first define 3D printing technology, investigate how 3D manufacturing is used to produce furniture and interior design elements by examining the basic components of 3D printing technology, and analyze the effects of materials and modern technology on furniture and interior design through examples. In the methodology of the study, a descriptive analysis method is used to define and analyze 3D printing technologies and the materials used with these technologies in furniture and interior design elements. The findings obtained from this study are expected to contribute to raising awareness about the production of furniture and interior design elements using 3D manufacturing. It is also aimed to provide interior architects and designers with a different perspective and a guiding path.

3D Printing Technologies

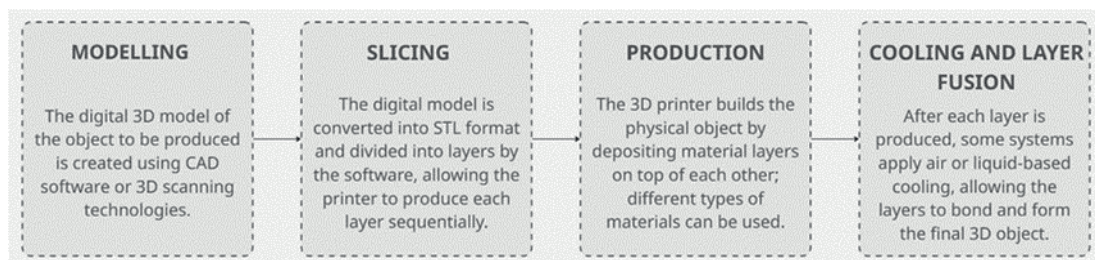
3D printing is defined as the process of manufacturing an object by adding thin layers of a selected material on top of each other by using data from a three-dimensional model designed in a digital environment (El-Sayegh et al., 2020). This technology is a form of manufacturing known as rapid prototyping technology or additive manufacturing (Yang & Du, 2022). The American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO) define Additive Manufacturing (AM) as a process in which physical objects are produced by joining materials layer by layer, based on three-dimensional model data created in a digital environment (El-Sayegh et. al., 2020). Compared to subtractive manufacturing methods, this new approach has significant advantages, such as the ability to produce solid parts with lower energy consumption, easier application of computer-aided process control compared to other production technologies, the direct production of physical parts from computer-aided design (CAD) models, significant savings in both time and cost, especially in prototyping processes, offering design optimization freedom, and being accepted as one of today’s most competent manufacturing technologies (Gedik et al., 2018; El-Sayegh

et al., 2020; Cengiz & Aktepe, 2022). Due to these features, 3D printing is currently considered an alternative method to traditional manufacturing techniques by producers. Current research includes discussions that the effects of 3D printing technologies may radically change not only production methods but also our design, consumption, and living practices; thus, it could be a pioneer of a new industrial revolution (Gedik et al., 2018).

Today, 3D printers are used in a very wide range of applications and hold significant potential, especially in furniture and interior design and their production processes. This technology stands out as an innovative manufacturing method that allows for the production of personalized designs and unique products. Furthermore, the use of 3D printers is not limited to design disciplines; they are also effectively used in the medical field for the production of prosthetics, dental implants, and biomedical devices, as well as in the prototyping processes of industrial design and machine parts. The production process of 3D printers is based on a working principle that consists of 4 main stages (Figure 1). These stages are modeling, joining, production, and cooling, respectively (Yıldıztepe & Arabacıoğlu, 2024). These stages can be briefly explained as follows.

Figure 1

Working Principles of 3D Printers (Yıldıztepe & Arabacıoğlu, 2024)



- 1. Modeling:** The first stage of the 3D printing process is the creation of a 3D model of the object to be produced in a digital environment. This model is designed through CAD software or obtained by utilizing 3D scanning Technologies (Yıldıztepe & Arabacıoğlu, 2024).
- 2. Slicing:** The created 3D digital model is converted into a Standard Triangle Language (STL) file type, which is a processable format for the printer. After this stage, the relevant software divides the model into layers and allows each layer to be produced sequentially by the printer (Yıldıztepe & Arabacıoğlu, 2024).
- 3. Production:** The 3D printer creates the object by adding layers of material one on top of another until a physical object is formed. This production process is carried out with the use of different types of materials (Yıldıztepe & Arabacıoğlu, 2024).
- 4. Cooling and Layer Unification:** After the production of each layer, some printer

systems use air or liquid-based cooling methods to solidify the layers. Following this process, the layers are integrated to produce the final 3D object (Yıldıztepe & Arabacıoğlu, 2024).

In the final stage of the production process, after the final 3D object is created, various finishing operations need to be applied. Depending on the properties of the material used and the geometric complexity of the product, some parts may require secondary processes such as sanding, filing, polishing, curing, material filling, or painting (Saad, 2016). 3D printing technologies include different production methods, and the fundamental distinction between these methods arises from the way the layers are created. The most commonly used 3D printing technologies include Selective Laser Sintering (SLS), Stereolithography Apparatus (SLA), and Fused Deposition Modeling (FDM) methods. In general, the key elements to be considered in the 3D printing process are production speed, the cost of the prototype, the economic dimension of the printer hardware, the type and cost of the material to be used, and the possibilities regarding color variety.

In the following section, a brief overview of evolving 3D printing technologies is provided. Additionally, in Table 1 created for the study, the types of 3D printing technologies are comparatively analyzed in the context of their 3D operating principles, materials used, advantages, and disadvantages.

An Overview of 3D Printing Technologies

Fused Deposition Modeling (FDM)

Fused Deposition Modeling (FDM) is a common manufacturing method based on the principle of melting a material through a heated nozzle and depositing it layer by layer. In accordance with the print paths derived from CAD data, molten plastic filaments are stacked one on top of another by a print head moving along the X, Y, and Z axes to create a solid object (Nadarajah, 2018). The advantages of this method include low hardware and material costs, ease of application, being the most common method, the ability to produce products with complex geometries, a wide range of material options, and the ability to process high-strength plastics. However, it has disadvantages such as surface roughness, low production speed, and issues with precision and material density (Saad, 2016; Şahin & Turan, 2018). In recent years, FDM's scalability has increased, and this has made it widespread in various sectors such as medicine, construction, and prototype production. In this method, thermoplastic filaments such as ABS, PLA, PETG, nylon, TPU, PC, and ULTEM are commonly used. Additionally, materials like steel, concrete, and wood have been adapted for this technology (Saad, 2016; Topal & Kavut, 2024; Eke, 2019).

Stereolithography (SLA)

Stereolithography (SLA) is an additive manufacturing method that begins with the

conversion of CAD data into STL format and is based on the layer-by-layer curing of photopolymer resin with a UV laser. The production process starts with a thin layer of photopolymer spread on a perforated platform, and this layer is selectively cured by a UV laser beam to form the first layer. The 3D model is completed by adding successive layers on top of each other using the same method, and the object is then removed from the tank. After production, the parts are cleaned with a solution to remove excess resin and then subjected to a UV curing process to complete polymerization (Nadarajah, 2018). The advantages of this method include high resolution, smooth surface quality, and the potential for rapid prototyping, while its disadvantages include high material and equipment costs, long printing times, and limited material variety (Canbolat & Aydın, 2019; Eke, 2019). SLA, which can be applied with resin-based photopolymers and materials similar to ABS, PC, and PP, is used in many sectors, especially medicine and manufacturing, for the production of prototypes and final products (Şahin & Turan, 2018; Chen et al., 2023).

Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is an additive manufacturing method based on sintering thin layers of powdered materials with a high-power laser. In the process, which begins with the conversion of CAD files into STL format, the laser fuses the powder particles together by heating them just below their melting point and creates a layered structure. This technology, developed by Carl Deckard and Joe Beaman in the 1980s (Nadarajah, 2018), offers advantages such as strong structure, high heat and chemical resistance, fast production, durable print quality, and the ability to create complex geometries without the need for support structures (Saad, 2016; Şahin & Turan, 2018; Eke, 2019). However, this method has some disadvantages, including high costs due to the use of a high-power laser, process complexity, limited precision dependent on powder particle size, and the need for additional post-processing due to rough surfaces. The method can be applied with various powdered materials such as ceramics, glass, composites, nylon (PA), aluminum, steel, sand, paper, and wood (Eke, 2019; Saad, 2016).

Selective Laser Melting (SLM)

Selective Laser Melting (SLM) is a technology based on the complete melting of metal powders with a high-density laser and combining them in a layered manner. The method offers advantages such as superior surface quality, high performance, the production of complex geometries, and the acquisition of lightweight and large-scale parts as an alternative to welding processes (Chen et al., 2023; Saad, 2016). However, the disadvantages of the method include limited production size, high cost, the need for support structures, and the requirement for additional post-processing for a smooth surface. SLM is commonly applied with metal powders such as titanium alloys, stainless steel, and aluminum (Saad, 2016; Chen et al., 2023).

Laminated Object Manufacturing (LOM)

Laminated Object Manufacturing (LOM) is an additive manufacturing method based on laminating layers of paper, plastic, or metal with heat and pressure, then shaping them with a laser or blade. The process is repeated until the model is completed by cutting layers that have been joined with adhesive according to the CAD data. This method, developed by Helisys Inc. in the 1980s, allows for low-cost, rapid prototype production and multi-color use (Nadarajah, 2018; Eke, 2019). However, the method has some disadvantages, such as low precision (Şahin & Turan, 2018), low material durability (Eke, 2019), and inadequacy with complex geometries. In LOM, various materials like paper (new or recycled), plastic foam, ceramics, and layers impregnated with metal powder can be used (Saad, 2016; Şahin & Turan, 2018).

Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering (DMLS) is a powder-based additive manufacturing method that allows for the direct production of complex metal components from CAD data. In this process, a CAD model, powder material, and energy input are primarily used; parts with high density, good surface quality, and superior mechanical properties are obtained by sintering each layer selectively with a laser. DMLS provides cost and time advantages in low-volume production by eliminating the need for molds. It also offers additional benefits such as design flexibility and reduced inventory costs by allowing parts to be stored digitally and produced on demand. However, it has limitations in the production of large-scale parts and often requires additional post-processing. The method is widely applied with materials such as titanium, aluminum, nickel alloys, stainless steel, and cobalt chrome (Venkatesh & Nandini, 2013).

Digital Light Processing (DLP)

Digital Light Processing (DLP) technology is based on the principle of solidifying liquid photopolymer resin on its surface by directing ultraviolet light through micro-mirrors. The simultaneous solidification of the cross-sectional area of the layers significantly increases production speed compared to laser-based scanning methods (Eke, 2019). While the DLP method offers advantages such as high resolution, production precision, and the ability to produce complex geometries, it has certain limitations due to limited material variety and restrictions on layer thickness. This technology primarily uses liquid photopolymer materials (Saad, 2016).

Rapid Liquid Printing (RLP)

Rapid Liquid Printing (RLP) is an additive manufacturing method particularly suitable for the production of small-scale products; however, its production capacity is limited on an industrial and commercial scale. This technology, developed in collaboration between MIT and Steelcase, focuses on speed, size flexibility, and the use of high-quality materials. RLP is based on the principle of directly injecting liquid material into a special gel medium and can work with various industrial liquids such as rubber, foam, and

plastic. The gel eliminates the need for support structures by holding the material in place and prevents void formation by self-restoring after the nozzle pass. The product hardens through a chemical reaction without requiring additional light or heat treatment and can be directly removed from the gel medium. Thus, designs can be produced faster without the necessity of layered manufacturing (Canbolat & Aydin, 2019).

3D Concrete Printing (3DCP)

3D Concrete Printing (3DCP) is a production method based on the layer-by-layer deposition of cement-based materials by extrusion devices. The print head typically moves horizontally on a large frame, while the extrusion apparatus places the pre-formulated mixtures layer by layer along the desired geometric contours. This method eliminates the need for molds, saves on material and labor, offers fast production capabilities, presents design freedom, and facilitates the production of complex curved forms. Its disadvantages include high hardware and initial costs, limited material variety, and weak inter-layer bonding (Girskas & Kligys, 2025). Besides concrete, materials such as plastic, sand, metal, clay, and recycled or local materials can be used in 3DCP. The technology has various applications, including the production of residential and infrastructure structures, bridges, panels, artificial reefs, furniture, and sculptures (Nadarajah, 2018).

Binder Jetting (BJ)

Binder Jetting (BJ) technology is an additive manufacturing method where a liquid binder material brings together powdered raw material layer by layer (Şahin & Turan, 2018). The structural material does not come directly from the printer but consists of a powdered raw material brought together by the binder. Although this method, first developed by the Massachusetts Institute of Technology (MIT), is called “3D Printing (3DP)” in the literature, it has not been registered as an official trademark. The licensing rights for the technology initially belonged to Z Corp, but they were later transferred to companies such as 3D Systems and ExOne. The method offers advantages such as support-free production and multi-color options, but it also has disadvantages such as high cost and limited mechanical strength. Ceramic, metal, plastic, sand and composite materials are commonly used in this technology (Eke, 2019).

PolyJet (Additive Modelling)

PolyJet technology is based on the principle of accumulating liquid polymers layer by layer by jetting them in fine droplets, and instantly curing each layer by UV light. This method enables the production of complex geometries with high precision and resolution, and stands out for its rapid prototyping capability, multi-material use, smooth surface quality, and user-friendly nature (Şahin & Turan, 2018). However, its main disadvantages include low mechanical strength, limited material variety, high cost, and the need for support structures (Gibson, et al., 2021). Photopolymer resins and acrylic

materials are used in this technology (Şahin & Turan, 2018).

Multi-Jet Printing (MJP)

Multi-Jet Printing (MJP) technology is based on the principle of depositing liquid photopolymer droplets layer by layer via print heads that operate on the logic of inkjet printers. The use of multiple nozzles makes it possible to print the main and support material simultaneously, and the ability to apply three different materials concurrently increases color and material variety. This method is prominent for its advantages of high resolution, smooth surface quality, multi-material combinations, and easily removable wax support material. However, it also has disadvantages such as limited production volume, high cost, and low mechanical strength. MJP technology can work with plastic, metal, and wax-based materials, and it is particularly preferred for low-volume end-use parts, prototype production, and assembly testing. Healthcare, automotive, consumer products, and household goods are among the common application areas of this technology (Eke, 2019).

Directed Energy Deposition (DED)

Directed Energy Deposition (DED) is an additive manufacturing technology based on the principle of melting and depositing metal powders or wires layer by layer with a high-energy heat source (laser, electron beam, or plasma arc) (Herzog et al., 2016). It is generally preferred for the production of large-scale parts, surface coatings, and repair applications. Functional gradient structures can be produced with multi-material printing, and the production process is not limited only to horizontal layers thanks to 4–5 axis systems (Eke, 2019). The main advantages of the method are its high production speed, suitability for large-part manufacturing, and the ability to combine different metal alloys in a single process. Its disadvantages are surface roughness, geometric limitations, high equipment cost, and the risk of porosity due to rapid solidification (DebRoy et al., 2018). Metallic materials such as titanium, aluminum, nickel, cobalt-chromium alloys, stainless steel, and similar materials are commonly used in the DED process (Liu et al., 2017).

Table 1

Comparison of 3D Working Principle, material properties and advantages and disadvantages of different 3D printing methods

3D Printing Technology	3D Working Principle	Basic Materials	Advantages	Disadvantages
FDM Fused Deposition Modeling	Filament melting and layering	Thermoplastic materials, ABS, PLA, Nylon, PC, ULTEM	The most popular technique, inexpensive, easy, complex geometry, flexible, resistant and durable, variety of materials	Rough product surface, low production speed, precision and material density

SLA Stereolithography Apparatus	Photo-polymerization	Resin-based materials, Liquid photopolymer, ABS-Like, PC-Like, PP, Like	high resolution and smooth surface quality, rapid prototyping, detailed models	Cost, long printing time, limited materials
SLS Selective Laser Sintering	combining powdered materials by distributing them in thin layers	Powder Material, Ceramic, Glass, Composites, Nylon PA, Aluminum, Steel, Sand, Paper, Wood	resistance to high heat, , high speed, durable print quality, complex geometries, chemical resistant, strong structure	Expensive, more complex, printing sensitivity is limited by the size of dust particles, rough surface finish due to the powder-based manufacturing process
SLM Selective Laser Melting	produced by melting metal powders with a laser and bonding them in layers	Metal powder and metal alloys,	Excellent surface quality performance, complex forming structure. the potential to replace welding applications, large and lightweight products	Limited size, high cost, The use of additional support elements in the production of complex geometries, Additional surface treatment processes must be applied to achieve a smooth surface.
LOM Laminated Object Manufacturing	Laser cutting and bonding of sheets	Plastic foam, Paper (new or recycled), Ceramic, Metal powder impregnated materials.	Rapid prototyping technology, cost-effectiveness, multi-colour usage	low precision, fragile material low precision and inadequacy in complex geometries
DMLS Direct Metal Laser Sintering	Powder bed fusion	Titanium, Aluminum, Nickel Alloy, Stainless Steel, Cobalt chrome, Maraging steel,	No mold requirement, cost efficiency, time savings, design flexibility, high surface quality, and mechanical strength	Surface roughness is high; final processing may be required, has limitations in the manufacture of large-volume parts,
DLP Digital Light Processing	Curing of photopolymer resin using UV light	Liquid photopolymer	Provides simultaneous production, complex shapes can be produced, provides high precision in production	Limited product variety, limited material variety
RLP Rapid Liquid Printing	Principle of direct liquid material injection within a gel suspension	Rubber, Foam, Plastic, Any industrial liquid material	Suitable for the production of complex geometries, fast and high-quality production	Limited production capacity on an industrial and commercial scale
3DCP (Concrete Printing)	Extrusion-based additive manufacturing	Concrete and Plastic, sand, metal, clay along with concrete	No formwork required, <i>Rapid production</i> , Material and cost savings, Design flexibility	Costs, limited material variety, weak interlayer bonding
BJ (Binder Jetting)	Filling powder-filled material sheets with adhesive liquid	Ceramics, sand, metal, plastic, composite	Unsupported material multi color	Cost, limited mechanical properties
PolyJet (Additive Modelling)	Photopolymer sputtering and UV curing	Acrylic, photopolymer resins	Complex geometry, high speed, high precision and resolution, easy to use, multi-material use, functional prototyping and suitable for office/home environments.	Low mechanical strength, cost, material limitations and support material requirements
MJP (Multi- Jet Printing)	layer-by-layer deposition of liquid photopolymer droplets	Plastic, metal, wax	High resolution and precision, use of resistant and flexible multi-materials, complex geometries,	limited material diversity, limited production volume, limited mechanical strength, high cost

DED (Directed Energy Deposition)	Layered deposition by feeding wire or powder through the nozzle and melting with laser/beam	Metal, cobalt-chromium, nickel, titanium, stainless steel, aluminium	large-scale parts, durable and final product, fast production, material flexibility	Surface roughness is high, geometric limitations, high equipment costs, risk of porosity and residue
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3D Printing Technologies in Furniture and Interior Design Elements

In recent years, 3D printing technology has made an impact across many sectors, especially food, construction, automotive, and healthcare. The number of sectors not directly affected by this technology has remained quite limited. This rapid development process has paved the way for radical transformations in the fields of interior design and furniture production (Eti Proto & Koç Sağlam, 2021). In this context, 3D printing technology not only offers an innovation in production methods but also initiates a new era in the design paradigm. Traditional furniture design and production methods are no longer considered sufficient alone and are being replaced by alternative approaches supported by innovative technologies. Accordingly, 3D printing technology presents significant potential by expanding the possibilities for original and personalized design in interiors (Yıldıztepe & Arabacıoğlu, 2024). This process, unlike traditional manufacturing in furniture and interior design, allows for production directly from digital data without the need for molds, assembly, or additional processing (Aydın, 2015). Within the context of interior design, 3D printing makes it possible to produce furniture pieces with personalized and complex geometries by enabling designers to seek original forms (Kang, 2015; Eti Proto & Koç Sağlam, 2021). This process, through rapid prototyping and small-scale production capabilities, allows designers to transform their ideas into physical form and experiment with different materials (Kang, 2015). Furthermore, the 3D printing process contributes to the development of efficiency in material use, sustainability, and a user-centered design approach (Cengiz & Aktepe, 2022). This technology, which goes beyond the mold-dependent production concept, allows furniture and spaces to acquire user-specific characteristics. Therefore, the use of 3D printing in interior design provides both transformation and advantages from various aspects in design practices (Yıldıztepe & Arabacıoğlu, 2024).

The emergence of new technologies has many advantages and disadvantages. This section will discuss the advantages and disadvantages of 3D printing technologies in furniture and interior design elements.

Advantages of 3D Printing Technologies in Furniture and Interior Design Elements

Personalization and Customization: This approach, which goes beyond standard production molds, allows for the development of innovative designs specific to each space and individual. Thus, it becomes possible to personalize interior spaces. It enables the 3D modeling and production of 3D designs, and in this way, it significantly contributes to

the development of customized products (Saad, 2016; Yıldıztepe & Arabacıoğlu, 2024).

Design Freedom and Production of Complex Geometry Products: 3D printing allows for the design and production of complex, organic, and unique forms that are difficult to achieve with traditional methods (Petrova & Jivkov, 2024).

Economic: Although 3D printing technology initially requires high equipment and setup costs, it eventually has a lower production cost compared to the labor-intensity and additional costs that arise in traditional production methods (Saad, 2016; Eti Proto & Koç Sağlam, 2021; Yıldıztepe & Arabacıoğlu, 2024).

Rapid Production and Prototyping: In contrast to the time-constraining nature of traditional production processes, 3D printers provides significant advantages in terms of both efficiency and continuity by rapidly converting designs into production (Aydın, 2015). Furthermore, the time to create a prototype from a model is shortened; the time elapsed from the modeling of the design to its physical realization is much lower compared to traditional methods (Petrova & Jivkov, 2024).

Reduced Material Waste and Sustainability: Traditional furniture production leads to high material waste due to cutting and shaping processes. In contrast, 3D printing technology reduces waste by using only the necessary amount of material and offers a sustainable production approach by allowing waste to be recycled and reused (Cengiz & Aktepe, 2022; URL-1). Moreover, parts produced with 3D printing can be up to 60% lighter compared to those produced with traditional methods, and provide an advantage in terms of both cost and environmental impact while maintaining the same strength (Saad, 2016).

Reduction of Storage Costs: Traditional mass production processes bring with them the need for storage and associated costs resulting from large-scale production. 3D printing technology significantly reduces storage requirements and costs in small-scale productions (Thomas & Gilbert, 2014).

New Material Combinations: 3D printing technology allows different raw materials to be used together by overcoming the limitations of traditional production methods regarding material combinations. Thanks to additive manufacturing, materials other than plastic have also become processable, and numerous materials with metal, ceramic, or glass appearances, various strengths, and heat resistance have become usable in design processes. This increases design freedom and supports functional and aesthetic diversity in production (Saad, 2016).

Disadvantages of 3D Printing Technologies in Furniture and Interior Design Elements

Surface Quality and Post-Processing Requirement: Due to additive manufacturing, layer lines on the final product can be visible, and the surface of the product produced with 3D printing is often rough. Therefore, the products require post-processing before use. Especially for interior design elements and furniture parts that are aesthetically prominent, post-processing activities such as painting, sanding, or coating are necessary (El-Sayegh et al., 2020).

Unauthorized Copying of Products: One of the most significant disadvantages of 3D printing technology is that it enables the production of counterfeit products. Consequently, this leads to intellectual property rights infringements. This technology allows any individual with access to the necessary design files and a 3D printer to become a producer. This situation complicates the detection of the source of counterfeit products and makes it significantly difficult for copyright and patent holders to protect their legal rights (Saad, 2016).

Scale Limitations and Production Speed: 3D printers have certain limitations regarding the dimensions of the objects created. While providing significant advantages in small and medium-scale projects, the production of large furniture pieces or high-volume mass production processes can take a long time. Consequently, in some cases, traditional production methods may be more efficient in terms of the advantages arising from the economic scale (URL-2).

Lack of Material Diversity: Compared to traditional materials used in furniture parts, the types of materials that can be used in 3D printing are still limited. Especially for advanced polymers, metals, and composites that can meet the requirements for durability, aesthetics, and mechanical performance, suitable options are either high in cost or have technical constraints in use (Petrova & Jivkov, 2024).

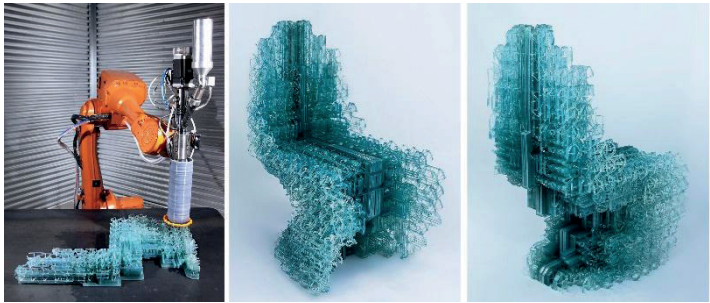
Furniture and Interior Design Elements Produced by 3D Printing Technologies and Their Analyses

In this section, furniture and interior design products manufactured using 3D printing technologies are distinguished. The analysis has been carried out in terms of the type of 3D printing technology examined, the material used and its properties, as well as the general application and presentation of the design. The evaluations of these analyses are provided in Table 2.

Table 2

Analyses of 3D Printed Products: Design, Designer, Design Concept, 3D Printer Materials, Material Properties, General Use, and 3D Printing Technology

Design Prototype/ Design Concept	Design: Bikechair Designer: Giorgio Gurioli.  -Design and Collaboration: The Bikechair was designed by Italian designer Giorgio Gurioli and produced using large-scale 3D printing technology; the project was realized in collaboration with WASP (World's Advanced Saving Project) (URL-3). -Exhibition: The product was exhibited at the Milan PLAST Fair in 2018. -Design Objective: The chair aims to provide an ergonomic and aesthetically pleasing seating experience while offering a posture suitable for passive exercise (URL-3). -Production Process: Large-scale printing was carried out using Delta WASP 3MT INDUSTRIAL 3D printers using thermoplastic granules provided by Eni Versalis; production time was approximately 10 hours (URL-3). -Material and Technical Characteristics: ABS (Acrylonitrile Butadiene Styrene) granules were used, with a 1 mm layer height ensuring detailed and smooth surface quality (URL-3). -Aesthetics and Functionality: The yellow ABS material provides a modern and dynamic aesthetic, while the ergonomic design offers user comfort. The design integrates digital production with traditional craftsmanship, reflecting the Maker Economy approach (URL-3).
Material	ABS (Optimized ABS in pellet form)
Material Properties	- Surface Quality: ABS models exhibit a rougher surface compared to other materials (Saad, 2016). -Water and Heat Resistance: ABS is water-permeable and can withstand temperatures up to approximately 105 °C (Saad, 2016; Şahin & Turan, 2018). - Dimensional Accuracy: The material allows for the production of precise and detailed parts (URL-4). - Surface Treatments: Smooth and aesthetic surfaces can be achieved by chemical treatment with acetone (Demircali et al., 2024). - Cost: ABS is a low-cost material (URL-5). -Safety Warning: It can release HCN gas at high temperatures; therefore, good ventilation is required during printing (Şahin & Turan, 2018).
General Use	-ABS filament is widely used in furniture connectors, prototypes, architectural models, consumer products, and component production (Petrova & Jivkov, 2024; Şahin & Turan, 2018). -Functional Capability: ABS is suitable for producing fully functional models; for example, Lego pieces are made from this material (Şahin & Turan, 2018). -Mechanical Properties: ABS is characterized by high strength and impact resistance (Demircali et al., 2024). -Material Advantages: The material is UV-resistant and is one of the closest options to real production materials (Saad, 2016).
3D Printing Technology	FDM (Fused Deposition Modeling)

Design Prototype/ Design Concept	Design: Voxel Chair V1.0 Designer: The design team is led by DCL's two co-directors, Manuel Jiménez Garcia and Gilles Retsin.  -Production and Exhibition: The Voxel Chair v1.0, produced in collaboration with Nagami. Design and Vicente Soler, is currently exhibited at Imprimer Le Monde at the Centre Pompidou, Paris (URL-6). Design Inspiration: The model was inspired by the iconic Panton Chair designed by Danish designer Verner Panton (URL-6). -Production Method: Unlike conventional additive manufacturing, software developed by the Bartlett Design Computation Laboratory (UCL) generates the design through robotic extrusion of a continuous 2.36 km-long PLA filament (URL-6). -Structural Characteristics: A robotic arm extrudes molten PLA directly into the air along computer-controlled paths; as the material cools and solidifies, it forms a lightweight, durable, and lattice-like structure (URL-6). -Material and Color: Transparent blue PLA filament was used in the prototype production (URL-6). Contribution of the Software: The system enables the fabrication of complex patterns while minimizing material consumption, thereby producing lightweight and efficient structures (URL-6).
Material	PLA
Material Properties	-PLA (polylactic acid) is a thermoplastic aliphatic polyester produced from renewable resources (URL- 7).
General Use	- PLA is a recyclable and environmentally friendly material (Şahin & Turan, 2018). - When mixed with different components, it can achieve wood- or plaster-like appearances (Şahin & Turan, 2018). - PLA material has lower strength compared to ABS material (Şahin & Turan, 2018). - Due to its slow solidification, printing errors may occur at high printing speeds; however, the use of cooling fans can mitigate these issues and enable higher printing speeds (Şahin & Turan, 2018). - It has lower heat resistance than ABS. (Şahin & Turan, 2018).
3D Printing Technology	Robotic 3D Printer

Design Prototype/ Design Concept	Design: Nadarra – 3D-Printed Sand Wall Designer: London-based architect and researcher Barry Wark.
	 - Exhibition:Nadarra is located at the entrance of the Dubai Future Museum (URL-8, URL-9). - Dimension and Structure: The wall measures 3X6 m and is composed of reusable modules (URL-8, URL-9). - Modular Design: The structure consists of puzzle-like panels that are easily assembled, manually transportable, and recyclable up to eight times (URL-8, URL-9). - Production Technique: The panels were produced using a binder jet printing method, which involves adding liquid binder to thin layers of sand particles (URL-8, URL-9). - Sustainability: The sand-based technology minimizes waste generation and enables the repeated fabrication, assembly, and recycling of the modules (URL-8, URL-9). - Environmental and Design Contribution: The prevention of material waste offers environmental benefits, while the method also allows the production of complex geometries without the need for molds (URL-8, URL-9).
Material	SAND
Material Properties	Production Technology: Production was carried out with the Voxeljet VX1000 3D printer used by the German 3D printer company Sandhelden; Quartz sand was used as the material (Kurşun & İpekoğlu, 1995). - Post-processing: After 3D printing, the object is strengthened and solidified by applying a liquid preservative, this process is called infiltration (Kurşun & İpekoğlu, 1995). - Material Properties: Quartz sand is a material found abundantly on earth (Kurşun & İpekoğlu, 1995).
General Use	-Quartz sand is used in different sectors such as glass, foundry and refractory industries (Kurşun and İpekoğlu, 1995). - In glass production, quartz sand must contain more than 99% SiO₂ and the amount of impurities must be stable (Aydın, 2021). - In casting systems, quartz sand must contain a minimum of 95-96% SiO₂ (URL-10). - When heated up to 1500 °C, quartz sand demonstrates high refractory performance (Kurşun and İpekoğlu, 1995).
3D Printing Technology	BJ (Binder Jetting)

Design Prototype/ Design Concept	Design: Gradient Fauteuil (3D printed concrete furniture), 2021 Designer: Philipp Aduatz  Dimensions: The dimensions of the design are 108 × 95 × 102 cm (URL-11). - Production Technology: The seating unit is produced using the 3D concrete printing method, enabling rapid production of complex forms without the need for molds (URL-11). - Ecological and Economic Contribution: Not using molds provides sustainability and cost advantages (URL-11). - Aesthetic Feature: During the printing process, pigments were injected into the concrete to create localized gradient color effects, resulting in each piece possessing a unique aesthetic transition (URL-11). - Structural Strength: The low tensile strength of concrete is strengthened by steel reinforcement in the design (URL-12).
Material	CEMENT
Material Properties	- Design Opportunities: 3D concrete printing enables the production of complex and innovative designs (URL-13). - Aesthetic Contribution: This method facilitates the creation of more aesthetic and original designs (URL-13).
General Use	- 3D concrete printing enables free-form, organic, and innovative furniture designs by eliminating traditional constraints such as molding or prefabrication (Buswell et al., 2018; Bos et al., 2016). - Concrete provides high mechanical strength, resistance to weather conditions, and long service life, particularly for outdoor furniture applications (Wolfs et al., 2019). - Thanks to additive manufacturing, production can be done without using molds, which reduces material waste and additional costs (URL-13). - Designers can develop user-specific forms, patterns, and dimensions with 3D concrete printing; this provides advantages in indoor and outdoor applications (Yıldıztepe & Arabacıoğlu, 2024; URL-13). - The low tensile and impact strength of concrete may lead to structural weaknesses in furniture applications (URL-13).
3D Printing Technology	Robotic arm-based 3D concrete extrusion printing method

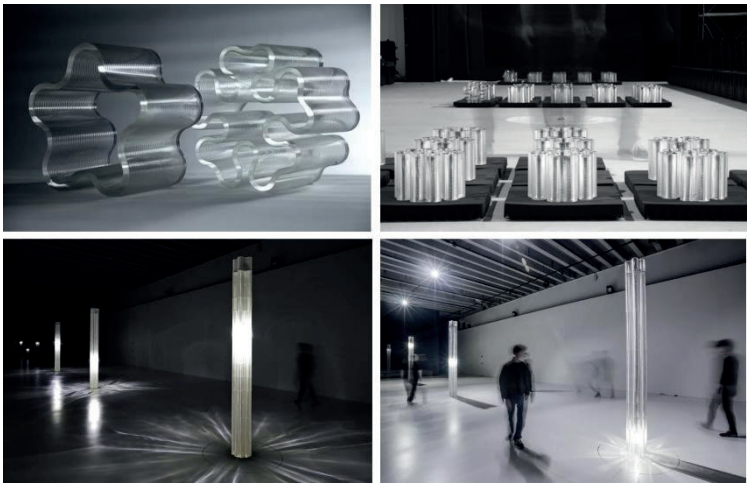
Design Prototype/ Design Concept	Design: Reform Lounge Chair Designer: Jurih Rahimkulov
	 -Design Approach: Reform Lounge Chair was designed with an aesthetic approach that integrates art, technology and sustainability (URL-14). - Production Method: Additive manufacturing (3D printing) technique, a computer-controlled process that deposits material in layers, was used in production (URL-14). - Digital Infrastructure: The design and software processes were developed using cloud-based platforms (URL-14). - Area of Use: The design can be used in both indoor and outdoor conditions (URL-14).
Material	WOOD (made of DuraSense®, a wood fiber-based biocomposite)
Material Properties	-Material Composition: The material contains cellulose fibers (URL-15). -Mechanical and Production Advantages: Cellulose fibers provide high strength, good printing performance and flexibility in finishing (URL-15). - Sustainability: The material is environmentally friendly and sustainable (URL-15).
General Use	-Wood and sawdust can be ground into fine powder and mixed with a binding material to be used in 3D printing (Cengiz & Aktepe, 2022). - Energy Efficiency: Wood exhibits lower energy consumption compared to steel and cement-based materials (Çankal & Şakar, 2021). - Wood is a natural and renewable resource and a sustainable building material with low carbon emissions and low energy requirements (Cengiz & Aktepe, 2022).
3D Printing Technology	Large-Scale 3D Printing

Design Prototype/ Design Concept	Design: Dragon Bench Designer: Joris Laarman (Joris Laarman Lab, Dutch, established 2004)
	 - Technological Innovation: Dragon Bench is one of the pioneering examples of 3D printing in metal processing. The design is produced with the MX3D robotic 3D printing system developed by Joris Laarman (URL-16, URL-17). - Production Method: The MX3D system is based on the principle of Wire Arc Additive Manufacturing (WAAM), which combines industrial robotic arms with welding technology (Canbolat & Aydın, 2019; Eke, 2019). - Material Diversity: This method enables the melting and solidification of metals such as stainless steel, aluminum, copper, and bronze into freeform lines without the need for support structures (URL-16, URL-17). - Furniture Design: Dragon Bench is one of the first examples of furniture produced with this technology and is considered as a hybrid research object that combines art, engineering and design (URL-16, URL-17). - Advantages: Compared to traditional furniture manufacturing, the method provides significant advantages in terms of cost and time efficiency by offering design freedom, material efficiency, parametric form generation, and the elimination of support structure requirements (URL-16, URL-17).
Material	STEEL
Material Properties	-Metal powders used in 3D printing technologies consist of micro- or nanoscale particles of metallic elements or alloys. These powders are employed in additive manufacturing processes through 3D printers (URL-18).
General Use	-Compared to conventional methods, 3D metal printing enables the production of more complex and flexible components (URL-18). -Metal powders are of critical importance for ensuring the desired alloy composition, properties, and mechanical strength (URL-18). -Metal tozlar lazer veya elektron ışını ile eritilir ve katmanlarla birleştirilir. -Various metal powders, such as titanium, aluminum, stainless steel, and nickel alloys, are utilized in this process (URL-18).
3D Printing Technology	MX3D-Metal 3D-Printing Robot

Design Prototype/ Design Concept	Design: Print To Build Designer: Gellert Olle (2017)
	 -Design Series: Gellert Olle's "Print to Build" series consists of modular connectors designed to join 8 mm thick plywood panels at angles of 90°, 45°, and 120° (URL-19). -Assembly Feature: The system is distinguished by its ability to be assembled without the use of screws or adhesives (URL-19). -Production and Weight: The connectors are produced via 3D printing, designed to accommodate different angles, with the heaviest component weighing approximately 30 grams (URL-19).
Material	POLYAMIDE (Powder)
Material Properties	Material Properties: Polyamide (nylon) is a widely used thermoplastic that provides toughness and flexibility, along with high impact and abrasion resistance (URL-20). Economic Advantage: Due to its low cost, polyamide is preferred in the production of functional parts using 3D printers (URL-21). -Production Method: Polyamide prints are produced from white, fine-grained powder (URL-22). -Mechanical Properties: The resulting products are durable and flexible, exhibiting resistance to minor impacts and bending (URL-23). Surface Texture: The surfaces have a sandy, granular, and slightly porous appearance (URL-24). Usage Limitation: Due to its moisture-absorbing property, polyamide is unsuitable for outdoor use; however, it can be rendered waterproof through specific treatments (URL-25).
General Use	-Application Area: Polyamide is suitable for the production of detailed and complex models (URL-24). Prototype Production: It is particularly preferred for small-scale prototypes (e.g., lamps, connectors) (URL-24).
3D Printing Technology	FDM (Fused Deposition Modeling)

Design Prototype/ Design Concept	Design: Aluminum Gradient Chair Designer: Joris Laarman
	 - Exhibition: The design is in the permanent collections of the National Gallery of Victoria in Australia and the Vitra Design Museum in Germany (URL-26). - Production Technology: The Aluminum Gradient Chair is the first non-plastic 3D-printed furniture produced by layering aluminum powder and compressing it with a laser (URL-27). - Design Feature: The chair employs a gradient cellular density approach based on biomimetic and generative design principles, providing high structural strength and lightweight performance. Additionally, its permeable surfaces contribute to light transmission and aesthetic transparency (URL-27).
Material	ALUMINUM (Powder)
Material Properties	-Material Composition: Aluminum powder represents a finely particulate form of aluminum metal (URL-28). -Material Properties: Aluminum is a low-density, lightweight, durable metal with resistance to oxidation (URL-28).
General Use	-Industrial Applications: Aluminum powder is utilized in a variety of industrial and commercial applications, including additive manufacturing (3D metal printing), powder metallurgy, coatings, paint production, and rocket propellants (URL-28).
3D Printing Technology	SLS (Selective Laser Sintering)

Design Prototype/ Design Concept	Design: Cool Brick Designer: Virginia San Fratello & Ronald Rael, 2015
	 -Design Inspiration: Cool Brick was inspired by the Muscatese Evaporative Cooling Window, which combines wooden shutters with ceramic vessels filled with water to provide passive indoor cooling in desert environments (URL-29). -Function: Porous ceramic bricks, which can be used as partitions or curtain walls in interior, absorb water and enable passive cooling through evaporation (URL-29). -Modular Production: The bricks were produced as a modular system through 3D printing (URL-29). -Working Mechanism: The 3D-printed bricks are joined with mortar; as air passes through the bricks, the water within the ceramic's micro-pores evaporates, thereby lowering the indoor temperature (URL-29).
Material	CERAMIC
Material Properties	-Production Method: Ceramic-based models are manufactured using alumina-silica powder, with their surfaces coated in porcelain and silica layers (Saad, 2016). -Aesthetics and Safety: A lead-free and non-toxic glaze applied after production ensures both surface gloss and user safety (Saad, 2016). -Heat Resistance: Depending on the composition of the clay, ceramic materials can be fired at temperatures ranging between 800°C and 4215°C, providing high thermal resistance (Yıldırım, 2021).
General Use	- Ceramics are widely used in building materials (bricks, roof tiles, tiles, ceramic slabs), household items (porcelain plates, cups, decorative objects, and vases), and in the production of glass and porcelain products. Additionally, they are employed in advanced technological applications within biomedical, electronics, energy, and defense industries (Yıldırım, 2021).
3D Printing Technology	LOM (Laminated Object Manufacturing)

Design Prototype/ Design Concept	Design: Glass I & Glass II (2017-2018) Designer: Neri OXMAN & Mediated Matter Group
	 -Exhibition and Installation: At the Lexus Yet exhibition during the Milan Salone del Mobile, the scalability of the Glass 3D Printing II (G3DP2) technology, developed by the Mediated Matter Group at the MIT Media Lab, was showcased. The system presents a material processing method applicable from desktop scale to architectural scale and potentially to the construction industry (URL-30). - Technological Advancement: Building upon the first-generation printer design developed in 2015, the G3DP2 system was introduced. The new platform offers a production area four times larger and the capability to process up to 30 kg of molten glass in a single print. Its integrated thermal control system preserves structural integrity during annealing and printing, while four-axis motion control enables geometric precision and the production of complex glass forms with variable extrusion thicknesses (URL-30, URL-31). -Architectural Forms: The installation includes light-dynamic columns composed of modular glass units, each 20 cm in height, stacked to form three columns approximately 3 meters tall. The columns exhibit continuously shifting geometries, with multiple lobe profiles that organically transition toward the base (URL-30, URL-31). - Structural and Aesthetic Features: Structurally, the columns function similarly to the columns of a multi-story building. The varied geometric profiles of each layer generate caustic light patterns through programmable LED illumination. Dark mirrored surfaces further enhance the visual effect, creating an illusion of infinity and light integration within the spatial environment (URL-30, URL-31).
	Material GLASS
	Material Properties Potential: Glass-based materials hold significant potential in additive manufacturing due to their hardness, optical performance, economic accessibility, and widespread availability. However, existing studies on glass additive manufacturing remain limited. To date, two primary technologies have been applied, each with inherent disadvantages. In particular, the high melting temperature and viscosity of glass have led to the development of the binder jetting method. Although sintered glass objects produced through this approach are commercially available, they exhibit high brittleness and insufficient densification, resulting in low light transmittance and an opaque appearance (Klein, 2015).
	General Use -Application Areas: Glass materials are utilized in architecture and construction, furniture and interior design, optical and electronic applications, healthcare and laboratory equipment, the packaging industry, as well as in art and design (Belis et al., 2019; Demirci & Akçay, 2023; Wiederhorn & Clarke, 2022).
	3D Printing Technology G3DP (Nozzle Extrusion)

Conclusion

Developments in technology-based modern design and production methods have created a significant transformation in interior design elements and furniture applications. In this context, 3D printing technology has become one of the increasingly prominent methods in the field of furniture and interior design, thanks to the facilities it provides in production processes. This technology not only increases efficiency in production processes but also provides designers and interior architects with the opportunity to realize more original, personalized forms that are difficult to produce with traditional methods. These developments offer notable improvements in terms of both speed and quality, as well as productivity. The fact that many designers have preferred this method in recent years can be considered a strong indicator of the transition from mass production to a personal production model. Thus, thanks to 3D printing, designers have the opportunity to realize their products with a unique production process in their own workshops. The increasing widespread use of 3D printing technology in the production of interior design elements and furniture will continue to allow for the development of innovative and sustainable solutions in terms of aesthetics and functionality.

This study, conducted using the descriptive analysis method, examined the materials used in 3D printing technologies, the applications of these materials in furniture and interior design elements, and the effects of the aforementioned smart technology on design. Furthermore, the effects of various products used with 3D printing in the field of interior design and furniture on designers worldwide were also evaluated within this framework. As a result of all these examinations, the evaluations are as follows:

- Product development is possible in the design process thanks to 3D printing technology.
- 3D printing technology offers design freedom to designers by providing the opportunity for creativity and original design development.
- 3D printing technology continues to increase the creative potential of designers by offering new production methods in furniture manufacturing.
- It allows for the production of complex and detailed designs that are difficult to produce with traditional methods.
- It enables the transfer and application of natural forms and structural orders into the design process.
- It allows for the application of the parametric design approach.
- Personalization is prioritized in 3D printing methods. It is predicted that the demand for personalized products will increase over time due to the monotony of mass production, and in line with this, the use of 3D printing technology is

expected to become widespread.

- Time management in the design process is optimized through modeling and prototyping.
- 3D printing in the production of interior design elements and furniture has high potential for rapid prototyping, especially in the production of detailed products, and provides benefits in terms of design flexibility and the reduction of production risks. Furthermore, 3D printing technology provides significant time and cost advantages in scaled prototype production, especially for system solutions.
- The use of recycled or local materials through 3D printing in the production of interior design elements and furniture plays an important role in achieving sustainable production and consumption balances. In this context, material waste is observed to be almost completely eliminated in the 3D printing process.
- Changing color, design, and other personalization options does not create an additional cost during the printing process.
- In terms of production speed, 3D printing methods are relatively slower compared to mass production techniques and thus require further development.
- Since production can be performed locally with 3D printing technologies, the need for global logistics of raw materials and products is significantly reduced.
- 3D printing technology will significantly transform the habits of designers, manufacturers, and consumers by increasing production speed and will reshape the way furniture is purchased.
- It will be possible for consumers to quickly have products such as chairs, tables, and accessories produced in local 3D printing workshops.
- It should be noted that 3D printing technology is limited to certain material types.
- The advantages and disadvantages of each material to be used with 3D printing technology should be investigated. Furthermore, the type of objects to be printed and the functional requirements these objects will meet should be taken into account.
- Each design should be analyzed in terms of the mechanical properties of the materials before being offered for sale.
- Although 3D printing technology causes significant transformations in the furniture industry, it is not expected to completely eliminate traditional production methods. Designers and manufacturers will continue to use 3D printing by integrating it with their traditional production capabilities.

Based on the results of this study, in the context of the development of 3D printing

technology, it is recommended that further research should be conducted on expanding material diversity, production using hybrid materials, and increasing production speed. Furthermore, it is foreseen that 3D printing technology will offer an innovative perspective, primarily to designers, but also to educators, students, and professional sector employees, and will form a dataset or reference plane for other scientific studies.

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About The Author

Tuba ARKAN DEMİRÖRS holds an integrated PhD degree in Architecture in 2023. She is guest instructor, in the Department of Interior Architecture at KTO Karatay University in Konya, Türkiye. Her main areas of interest are materials and technology in architecture and interior architecture, building materials and interior architecture design.

E-mail: tuba_arkan@hotmail.com, **ORCID:** 0000-0003-3278-9045

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