FURN5.●

Handbook for facilitating the adoption of Industry 5.0 practices in the EU furniture industry

A Guide for advancing human-centric, sustainable, and resilient smart manufacturing

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Acknowledgement

Human-centric

Industry 5.0

Resilient

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Industry 5.0 and the intelligent future of furniture

Industry 5.0 represents the next evolution of modern manufacturing, moving beyond the traditional goals of efficiency and productivity to embrace a more **human-centric, sustainable, and resilient** approach. In simple terms, Industry 5.0 is about *using advanced technologies in a way that empowers workers, benefits society, and respects the environment*. This introductory chapter explains what Industry 5.0 means for the furniture sector, the key enabling technologies behind it, and a collection of relevant applications presented later in the report. This FURN5.0 handbook offers furniture industry executives and technicians practical, validated tools for the strategic Industry 5.0 transition, addressing the critical challenge of attracting and retaining talent, while improving worker well-being. Through practical examples, industry executives and technicians will gain a clear vision of the furniture industry's smart future and learn about concrete actions they can implement to boost digitalization and industry competitiveness.

What is Industry 5.0 in the furniture sector?

Industry 5.0 is a new industrial paradigm formulated by the European Commission that *"aims beyond efficiency and productivity as the sole goals"* of manufacturing. Instead, it **places the well-being of workers at the center of production and pursues broader societal and environmental goals**, complementing the existing Industry 4.0 framework. In essence, Industry 5.0 is built on three main pillars: **human-centricity, sustainability, and resilience** (see Figure 1). FURN5.0 promotes worker well-being, improved safety, and necessary skills development. This human-centric approach strengthens critical social dialogue for a socially fair EU industry transition. This means that factories of the future are not only smart and automated, but also designed around people's needs, ecologically responsible, and capable of withstanding disruptions.

1 *The three core pillars of Industry 5.0*

First and foremost, Industry 5.0 in the furniture sector is **human-centric**. Rather than treating technology as a substitute for people, it enhances human skill and creativity. Collaborative robots take on repetitive or hazardous tasks; intuitive interfaces such as AR/VR make training, setup, and problem-solving clearer and faster; and knowledge tools help workers access and share expertise. The result is safer, cleaner workplaces and roles that are more attractive to new talent, supporting upskilling and inclusion across the workforce.

Building on Industry 4.0's digitalization, Industry 5.0 reframes adoption around worker well-being, quality of work, and meaningful human–machine collabora- tion, while also enabling mass customization guided by craft and design intent. These human-centric gains naturally connect to broader objectives: resilient operations through data-driven decisions and interoperable systems, and sustainability through reduced waste, smarter materials choices, and lifecycle transparency (e.g., digital product passports). The European policy landscape — reflected in initiatives like FURN5.0 — encourages this transition, not only by promoting enabling technologies but also by supporting social dialogue, skills development, and an appealing vision of modern manufacturing. In short, Industry 5.0 aligns advanced technology with better jobs, better, more sustainable products, and responsible growth, placing people at the center while strengthening competitiveness and environmental performance.

Secondly, Industry 5.0 in the furniture sector is also aligned with **sustainability** (e.g. circular design and resource efficiency). European initiatives such as the Green Deal and the new Clean Industrial Deal and the Competitiveness Compass and other regulations are pushing furniture makers to reduce waste and document products' environmental footprints. In Industry 5.0, technology becomes a means to these purposes: for example, using **data and sensors to monitor energy and material usage**, or adopting **circular materials and processes** to minimize environmental impacts. In short, Industry 5.0 offers a *"vision of industry that (…) uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet"*. For furniture companies, this could mean designing products for longevity and recyclability, using bio-based materials, and leveraging smart systems to optimize production in an eco-friendly way.

Finally, **resilience**—the third pillar—is highly relevant to furniture manufacturing in a post-pandemic, globalized world, and it extends beyond factory walls to the territory where firms operate. Building resilience means greater production flexibility, transparent and diversified supply chains, and agile, continuously upskilled workforces. It also means anchoring value locally: strengthening regional supplier networks, shortening logistics routes, and fostering industrial symbiosis (e.g., shared services, circular material loops, and energy communities). Industry 5.0 encourages revising value chains and energy practices not only to withstand shocks but to co-develop with the local ecosystem, which is exactly the competitiveness effect long highlighted by cluster theory (as formulated by Michael Porter), where deep ties between companies, institutions, and talent raise productivity and innovation. In furniture, this translates into capabilities such as rapid product-line switching,

cross-training teams with digital skills, and using digital platforms to source and sell while prioritizing regional partners; it also includes mapping provenance, developing second-source options nearby, and leveraging cluster organizations for shared testing, training, and market access. The result is a sector that is more robust to disruptions—and more competitive—because it is embedded, collaborative, and locally regenerative.

Overall, Industry 5.0 in furniture sector aligns technological innovation with a broad spectrum of human skills and capabilities—creativity, craftsmanship, critical judgment, problem-solving, collaboration, adaptability, and continuous learning—together with environmental responsibility, so the sector can thrive economically, socially, and ecologically.

Enabling technologies driving Industry 5.0

Industry 5.0 is powered by a suite of advanced **enabling technologies** that make its human-centric and sustainable vision possible. Many of these technologies are evolutions of Industry 4.0 tools, now applied in smarter, more collaborative, and more empathetic ways, thus placing human needs, well-being, and creativity at the core of industrial innovation. According to the European Commission, key technologies underpinning Industry

5.0 include **"customized human-machine interaction, nature-inspired technologies and intelligent materials, digital twins and simulation, technologies for data transmission/storage/analysis, artificial intelligence, and technologies for energy efficiency and autonomy"**. In practice, the following technological areas are especially relevant in the furniture manufacturing context:

Collaborative Human–Machine Interaction

A hallmark of Industry 5.0 is that humans and machines work together seamlessly. This includes the use of **collaborative robots (cobots)** that operate side by side with workers on the factory floor. Unlike traditional industrial robots that stay behind safety fences, cobots are designed with sensors and limits on force so they can safely share workspace with people. They take over heavy, repetitive, or ergonomically difficult tasks – for example, lifting heavy panels, sanding large surfaces, or performing precise drilling – thereby **improving worker safety and efficiency**. Crucially, these robots are *"collaborative and cognitive,"* meaning they can adapt to human intentions and provide feedback (e.g., using AI to interpret a worker's actions or voice commands). Alongside robotics, advanced **human–machine interfaces** like Augmented Reality (AR) and Virtual Reality (VR) are empowering workers in the furniture industry. AR/VR can overlay digital information onto the real world or simulate virtual environments, which proves *"useful for training, maintenance and design"* tasks in manufacturing. For instance, a new furniture assembler might wear AR glasses that display assembly guidelines step-by-step, or a product designer might use VR to walk through a virtual prototype of a new furniture piece. These intuitive interfaces make it easier for employees to interact with complex machines and processes, embodying the Industry 5.0 ideal of *"individualized human–machine interaction."*

Intelligent and Sustainable Materials

Industry 5.0 also embraces **nature-inspired and smart materials** to innovate products and reduce environmental impact. "Intelligent" or smart materials can react to their environment – for example, fabrics that change properties with temperature, or wood composites embedded with sensors. In furniture, this could mean **smart functionalities embedded into furniture pieces** (such as a table that can charge devices or adjust height automatically, or chairs that monitor posture). It also includes bio-based materials and *circular materials* (recyclable, renewable resources) that align with sustainability goals. By using advanced materials, furniture manufacturers can create products that are more durable, customizable, or environmentally friendly. This technology area often overlaps with design innovation: engineers are experimenting with **biomimicry** (learning from nature's designs) to create furniture materials that are light but strong, or with self-healing coatings that extend product life. While these "nature-inspired technologies and intelligent materials" might not be as visibly high-tech as robots or AI, they are a crucial part of Industry 5.0's push for sustainable innovation. A furniture company adopting Industry 5.0 might explore, for example, **wood-like composites made from recycled fibres** or **smart textiles** that respond to user needs, thus marrying old-world craftsmanship with new-age tech.

Digital Twins and Simulation

A digital twin is a **virtual replica of a physical product, process, or entire factory**. Industry 5.0 leverages digital twins and advanced simulation to optimize production and predict outcomes without expensive trial-and-error in the real world. In the furniture sector, digital twins can be game-changing. Imagine a digital model of a furniture piece that updates in real time as the product is manufactured, therefore allowing engineers to test adjustments virtually or foresee maintenance needs. Likewise, factories can have digital twins of their production lines to simulate workflow changes or integrate a new machine into software before doing it on the shop floor. One special application relevant to Industry 5.0's sustainability goal is **simulating environmental and social impacts**. Before implementing changes to materials or processes, companies can use software to model how these changes will affect their carbon footprint, waste output, or even worker ergonomics. The FURN5.0 project highlights technologies for *"simulation and measurement of environmental and social impact,"* underlining the importance of using digital tools to drive sustainability in design and production. Adopting digital twin technology enables furniture makers to become more **proactive and data-driven**, solving problems virtually (such as modifying a design to use less material) and ensuring optimal outcomes in terms of both efficiency and sustainability.

Data Connectivity and Traceability

Under Industry 5.0, **data is the connective tissue** that links all parts of the value chain. Building on IoT (Internet of Things) from Industry 4.0, furniture factories will employ networks of sensors and smart devices – on machines, in warehouses, even on delivered products – to gather real-time data. The goal is to create a continuous feedback loop for improvement and transparency. Using **IoT and Big Data to collect and analyse information in real time can greatly improve resource management** and **decision-making**. For example, sensors on a production line might track energy use, and analytics can then suggest ways to save power or schedule maintenance at optimal times. Another critical aspect is **interoperability,** which means that different machines and software systems sharing data seamlessly across the factory and supply chain. Industry 5.0 promotes *"data and system interoperability"* so that all stakeholders (from material suppliers to retail outlets) can be connected in a digital ecosystem. One concrete initiative in Europe that exemplifies data-driven transparency is the **Digital Product Passport (DPP)**. In essence, a DPP is a digital record accompanying a product, containing detailed information about its materials, origin, manufacturing, and end-of-life instructions. In the near future, furniture companies

will be required to provide such data for each product to comply with sustainability regulations. Scanning a simple QR code on a piece of furniture could reveal its entire "life story," enabling circular economy practices like easier recycling and responsible sourcing. In our context, **product traceability through a DPP is a key application** that ensures every step of a furniture product's life is transparent. This not only helps the environment but also adds value to consumers who want to know how their furniture was made. Overall, robust data infrastructures – from IoT sensors on the factory floor to cloud platforms aggregating big data – are foundational technologies enabling the *smart, connected, and transparent* nature of Industry 5.0.

Artificial Intelligence and Automation

AI is the engine that makes sense of all the data and complexity in Industry 5.0 systems. In a human-centric framework, Artificial Intelligence acts as an augmenting tool for human decision-making and creativity. There are two broad categories of AI applications here: *analytical AI* and *generative AI*. Analytical AI refers to using machine learning algorithms to detect patterns, predict outcomes, and support decisions. For a furniture manufacturer, analytical AI might be applied to demand forecasting, quality control, or process optimization – for instance, an AI system that analyses production data to predict machine failures or to flag defects in materials (improving resilience and quality). One of the applications described in the FURN5.0 handbook focuses on *"AI analytics and pattern analysis,"* analysing how AI can sift through large datasets to find trends that humans might miss. Generative AI, on the other hand, involves AI systems that can create new content or designs. This is a burgeoning area with exciting prospects not only for furniture design and marketing, but also for organizational efficiency. Imagine an AI that can generate hundreds of custom furniture design variations based on a customer's preferences or rapidly produce prototypes in a virtual environment, something that could greatly speed up the design phase. Such *"Generative AI for custom design and fast prototyping"* is one of the applications featured in this project. Similarly, generative AI can be leveraged to improve operational management and efficiency, for instance, by streamlining and creating new forms of knowledge management, automating documentation, and improving customer interaction. For instance, an AI-driven knowledge system could allow employees to query a database in natural language (like an AI assistant that knows the company's design rules and past projects). In sales and marketing, generative AI tools can automatically create personalized marketing content or interior design visualizations for clients, enhancing the customer experience. The common thread is that AI, when used responsibly, amplifies human capabilities – whether it is creativity in design or efficiency

in production – rather than replacing the human role. Industry 5.0 emphasizes *"a human-centric approach for digital technologies including AI"*, ensuring that AI soltions are developed with the worker's well-being and empowerment in mind.

Sustainable Energy and Autonomy

Rounding out the technology set are innovations in **energy efficiency, renewable energy, and autonomous systems**. While not unique to the furniture sector, these technologies are vital for achieving the sustainability pillar of Industry 5.0. This can include everything from factories installing solar panels and smart energy management systems to reduce their carbon footprint, to exploration of autonomous logistics (like self-driving forklifts or delivery drones) that can increase resilience in operations. Energy-focused tech did not feature as a standalone section in the FURN5.0 handbook, but it underpins the broader context: ultimately, many Industry 5.0 improvements (including efficient machines, optimized processes via AI, use of digital twins to cut waste) contribute to **energy savings and greener production**. European Industry 5.0 strategy explicitly calls out the importance of "technologies for energy efficiency, renewable energy, energy storage and autonomy" as part of this future industrial model. In a furniture factory, for example, this might manifest as adopting smart HVAC and lighting that respond to real-time conditions, or using energy harvested from production processes to power other operations. The emphasis is that technology should help minimize the environmental footprint of manufacturing, therefore achieving *sustainability* not just through materials, but also through how we power and run our factories.

In summary, Industry 5.0's enabling technologies form an interconnected toolbox.

Collaborative robotics and AR/VR focus on the *human* aspect, smart materials and clean tech target *sustainability*, and digital twins, IoT, AI ensure *resilience* and intelligence. Importantly, many of these technologies are already emerging in advanced companies today (as a 2024 report notes, they *"are already present in companies well along the digitalization path"*). However, Industry 5.0 envisage their adoption across the manufacturing sector in an integrated, people-first manner. For furniture companies embarking on this journey, understanding these technologies is the first step. Yet, recent research shows there is a **knowledge gap**: on average, *50% of surveyed EU furniture companies admitted knowing little about Industry 5.0 technologies (with some technologies having up to 70% low-awareness)*. This is where the FURN5.0 project's educational materials come in as useful resources by helping to bridge that gap by illustrating what these innovations mean in practice.

What to expect in this handbook - Applications overview

The core of the FURN5.0 project's handbook is a collection of **Industry 5.0 applications** – concise, practical case studies or fact sheets – each highlighting a specific application of Industry 5.0 technology in the furniture sector. These applications are designed to be easily readable and informative, so that furniture manufacturing business executives, employees, or any other interested readers can quickly grasp how a given technology works and what benefits it offers. This introductory chapter provides an outline of the sections in the handbook, explaining the types of contents covered and how to navigate them.

The applications are organized by technological domain, aligning with the enabling technology categories discussed above. This thematic grouping helps readers connect related topics and see the bigger picture. The main domains and their associated applications are as follows:

Human–Machine Interaction and Robotics

The content under this domain showcases how furniture manufacturing can become more human-centric through *collaborative robotics and immersive interfaces*. For example, a specific application focuses on **Human-Robot Interaction (HRI)** (No. 1) in furniture factories, showing how *collaborative robots ('cobots')* can assist workers in tasks like assembly or surface finishing. Another application covers the use of **Extended Reality (XR)** (No. 2) – i.e., Augmented and Virtual Reality – in product design and prototyping. There is also an application on **leveraging XR for workforce training and upskilling** (No. 3) in the furniture industry. Through these examples, readers will see how operators can work *hand-in-hand with smart machines*: from using AR glasses to visualize a new kitchen design in 3D before it is built, to programming a cobot by simply guiding it through a motion (rather than complex coding). The takeaway is that Industry 5.0 technologies can make the factory environment more interactive, intuitive, and safe for people.

Smart Materials and Functionalities

Under this domain, one of the applications is dedicated to **smart functionalities applied to the furniture sector** (No. 4), exploring advanced materials and embedded technologies that give furniture new capabilities. For instance, it might showcase smart furniture prototypes like a **table that integrates wireless charging and sensors**, or the use of **shape-memory materials** that allow components to self-adjust. The content will highlight how intelligent materials can add value (furniture that adapts to users or environment) and improve sustainability (materials that last longer or are easier to recycle). By reviewing this application, industry executives and technicians will understand the concept of *"intelligent materials"* in Industry 5.0 and how material science is as important as computer science in building the future of furniture.

Digital Twins and Simulation

Two applications fall into this domain, illustrating the power of virtualization and modelling. The first covers **digital twins of products and processes** (No. 5) and explains how creating a digital mirror of a furniture piece or an entire production line can help in design, testing, and maintenance. The second is about **technologies for simulation and measurement of environmental and social impact** (No. 6) in furniture manufacturing. This application is particularly forward-looking: it shows tools that can simulate a process (like finishing a table) and calculate its carbon emissions or even ergonomic impact on workers. Readers will learn how digital simulations can guide decision-making toward more sustainable and ergonomic production setups. Together, these applications emphasize a key Industry 5.0 idea: *"measure twice, cut once"*, i.e., use digital models to perfect processes and products virtually, saving time and resources in the real world.

Data Integration and Traceability

This domain encompasses the data-driven backbone of Industry 5.0 in furniture. Several applications address it from different angles:

- **Product Traceability through the Digital Product Passport (DPP)** (No. 7): one of the applications introduces the concept of a Digital Product Passport for furniture. It details how a DPP system can track a piece of furniture from raw material to end-of-life, storing information such as wood origin, adhesives used, carbon footprint, and recycling instructions. This is directly tied to upcoming EU sustainability regulations and shows a practical tool for compliance and transparency.
- **Data Processing for Learning Processes** (No. 8): this application examines how companies can turn raw data into actionable knowledge in Industry 5.0 where factory, machines and systems generate vast data; this section discusses methods like machine learning or data analytics that *learn* from production data to optimize

operations (for example, analysing production line data to identify inefficiencies or training AI models to predict quality issues). It highlights that simply collecting data is not enough – one must process and *learn* from it for continuous improvement.

- **Data and System Interoperability** (No. 9): this application deals with the challenge of integrating various IT systems and equipment so that they communicate effectively. In many furniture companies, design software, manufacturing execution systems, inventory databases, etc., might be siloed. The application will cover strategies or standards for interoperability (such as using common data formats or IoT platforms) to achieve a more connected factory, thus becoming a stepping-stone to Industry 5.0 where everything is linked in a digital ecosystem.
- **IoT and Sensor Integration in Production and Products:** Two closely related applications focus on networking sensors, one at the **manufacturing chain level** (No. 10) and one at the **product level** (No. 11). The first shows how integrating IoT into the production process (the factory floor) enables real-time monitoring and smarter automation. For instance, sensors on machinery can enable predictive maintenance – anticipating breakdowns before they happen – thus improving resilience. The second addresses **IoT in furniture products** themselves. This could range from smart office furniture that adjusts to ergonomic preferences, to connected home furniture that interacts with user devices. By grouping these topics together, readers can appreciate the full scope of connectivity: from internal processes to the end-user experience, data flows up and down the value chain. Overall, the sections in this data/traceability set demonstrate how **information becomes as important as the physical product** in Industry 5.0, enabling traceability, smarter decision-making, and new services.

Artificial Intelligence Applications

The contents included in this domain dive into **AI-driven innovations** in the furniture industry. Four applications illustrate distinct use cases of AI:

- **Generative AI for Custom Design and Fast Prototyping** (No. 12): This application discusses how generative algorithms can create design variations or even visual prototypes rapidly. For example, an AI could generate dozens of chair designs based on a designer's brief or even based on consumer feedback, significantly speeding up the iteration process. It might include examples of AI-generated furniture designs or how 3D printing can be combined with AI to prototype swiftly.

- **AI-Driven Knowledge Management Systems** (No. 13): Here the focus is on using AI to capture and organize knowledge within a furniture company. This could mean an intelligent database that uses natural language queries (allowing employees to ask questions like *"How was this model's upholstery issue resolved last year?"* and get answers from past records), or AI chatbots that assist in training new staff by answering technical questions. It shows AI as a support tool to retain expertise and guide employees, aligning with the human-centric ethos.
- **Optimizing Marketing and Sales with Generative AI** (No. 14): This application reviews the customer-facing side, showing how AI can personalize and automate content. Furniture retailers and manufacturers often need to produce catalogues, room visualizations, or marketing copy – generative AI can automate parts of this, creating tailored marketing materials for different audiences or interactive room designs for clients in real time. It exemplifies how, even beyond the factory floor, AI can add value in the furniture industry by enhancing customer engagement and unlocking creativity in marketing.
- **AI Analytics and Pattern Analysis** (No. 15): The last AI application deals with using AI for data analysis and decision support. It covers the use of advanced analytics or machine learning to find patterns in complex datasets – such as trends in consumer preferences, patterns in machine performance, or supply chain bottlenecks – and to support managers in strategic decisions. By implementing such analytical AI, furniture companies can move toward data-driven strategies, making the business more resilient and responsive to change (a key Industry 5.0 outcome).

By exploring these AI-focused applications, readers will gain insight into how **artificial intelligence serves as a versatile tool in Industry 5.0** – from creative design all the way to smarter business operations – always with the goal of complementing human skills and improving productivity in a sustainable way.

FURN5.0 handbook: content structure

The contents in the FURN5.0 handbook are structured under the five technology domains indicated above:

2 *FURN5.0 handbook Content Structure*

The following table summarizes the above-mentioned (numbered) applications included under each technology domain.

3 *FURN5.0 handbook applications*

Contents follow a **logical flow starting from human-machine interaction technologies, moving through digital infrastructure, and culminating in AI**. Within each domain, individual sections address specific applications as described.

This classification has two advantages:

It **mirrors the structure of Industry 5.0 technologies** introduced earlier, reinforcing the reader's understanding by grouping related topics (for example, after reading about collaborative robots and AR/VR in the intro, the reader will immediately find the corresponding section in the HMI section).

It highlights the **interconnections** between sections. Readers interested in a particular aspect (e.g., connectivity) can easily find all data-related sections together, thus obtaining a comprehensive picture of how traceability, interoperability, and IoT collectively contribute to a connected Industry 5.0 ecosystem.

Some applications span multiple domains (for example, a cobot uses AI for vision, or an AI design tool might also be a form of human-machine interaction). In such cases, the classification is based on the primary focus of the section. The proposed order is not the only way to arrange the content, but it provides a clear and pedagogical flow from the tangible shop-floor innovations (robots, materials) through to the digital and intangible innovations (data, AI).

Summary

This introductory chapter is meant to help readers navigate through the FURN5.0 handbook applications. The handbook outlines what Industry 5.0 means – particularly for furniture makers – and identifies the key technologies enabling this transformation. In summary, the focus of **Industry 5.0 is on integrating advanced technology with a human touch and an environmentally conscious approach**: it is the furniture factory where craftsmen work alongside cobots, where design is accelerated by AI but inspired by nature and sustainability, and where every product carries a passport of its sustainable journey. The fifteen applications included in the handbook illustrate these concepts with concrete examples and use cases.

By presenting applications in a structured way (grouped by domain), readers can easily find topics of interest and understand how each piece fits into the bigger Industry 5.0 picture. Whether a furniture company manager or technician assessing an innovation strategy, an employee curious about the future of their work, or simply an enthusiast of smart design, there is something to learn from each section. **The era of Industry 5.0 in furniture**

2

FURN5.0 applications handbook content structure

1	Human-Machine Interaction
2	Smart Materials
3	Digital Twins and Simulation
4	Data Integration & IoT
5	Artificial Intelligence

3

FURN5.0 applications

1	Human-Robot Interaction (HRI)
2	Extended Reality (XR)
3	Leveraging XR for workforce training and upskilling
4	Smart functionalities applied to the furniture sector
5	Digital twins of products and processes
6	Technologies for simulation and measurement of environmental and social impact
7	Product Traceability through the Digital Product Passport (DPP)
8	Data Processing for Learning Processes
9	Data and System Interoperability
10	IoT and Sensor Integration in Manufacturing chain Production and Products
11	IoT and Sensor Integration in Products
12	Generative AI for Custom Design and Fast Prototyping
13	AI-Driven Knowledge Management Systems
14	Optimizing Marketing and Sales with Generative AI
15	AI Analytics and Pattern Analysis

is dawning, and it promises a future where technology and craftsmanship join forces to create a smarter, more sustainable, and more human-cantered furniture industry.

Ultimately, the FURN5.0 project aims to equip stakeholders with the knowledge and tools to navigate this transition. By understanding the insights in these sections, industry executives will be better prepared to participate in shaping an "intelligent future of furniture."

Welcome to Industry 5.0!

Applications of Industry5.0 technologies

A Guide for advancing human-centric, sustainable, and resilient smart manufacturing

Human-Robot Interaction (HRI) in furniture industry

1
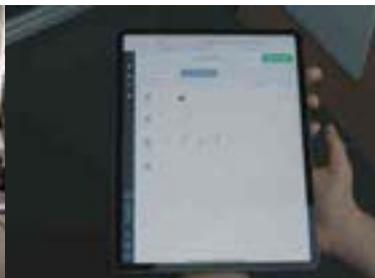
Implementation difficulty: **Low**
Economic viability: **Medium-High**

Human-Robot Interaction (HRI) in furniture industry

Description

In the transition towards Industry 5.0, human-robot interaction evolves beyond physical collaboration to embrace cognitive interaction, intuitive control, and real-time human empowerment. In the furniture manufacturing sector, this implies robots and AI systems designed to adapt to human needs, skills, and intentions, rather than requiring workers to adapt to the machine.

[1] *Techman Robot collaborative arm performs screwdriving operations guided by its integrated artificial vision system for automated assembly. Source: Techman Robot*

In light of this, the first approach of robotics towards Industry 5.0 is that it must be collaborative with humans. Collaborative robots are those that comply with the ISO10218 and ISO TC 15066 standards. These are robots designed to limit their force and impact energy. Unlike traditional industrial robots (which usually operate behind safety fences), cobots incorporate force sensors and motion limitation functions so that they can safely share a workspace with people. Some of the most relevant features to consider with these robots are payload capacity, range and repeatability to facilitate heavy tasks that require precision.

Collaborative robotics is necessary but not sufficient for the demands of robotics for Industry 5.0. Robotics must be equipped with the capacity for intelligent reasoning, ensuring it can provide the human with ongoing environmental situational awareness. Cognitive robotics takes advantage of the current context of AI as an emerging technology to interpret human actions, environmental data, and production context, enabling adaptive behaviors (e.g., adjusting force actuation depending on material hardness or defect detection while informing the human).

At this juncture, it is pertinent to acknowledge the significance of non-invasive reporting in conjunction with the provision of comprehensive environmental information and machine intentions to humans. Strategies such as Looming provide operators with a visual display of robot motion plans, upcoming movements, and intentions (light projections on the workspace), ensuring they always know what the robot is about to do, thereby reducing uncertainty and stress.

[2] *Universal Robots' UR5 collaborative robot testing the Looming strategy. The human can observe the light projections on the ground to know the intention of the robot's movement. Own source.*

Another strategy for robot-human interaction is through the integration of conversational AI. Natural language processing models enable operators to pose questions to the robot, issue instructions, or request explanations in natural spoken language, thereby facilitating intuitive and accessible control. This approach ensures that operators are always aware of the robot's upcoming actions, thereby minimising uncertainty and stress.

Human-Robot Interaction also entails equipping the operator with the skills and capabilities to control the robot. This is achieved by simplifying robot controls. These concerns the automatic generation of robot trajectories from visual formats of a part or the assembled piece of furniture. This is an effective solution for surface treatment operations, where the path is automatically generated from a CAD file.

[3] *Simulation of an automatic trajectory generation system that programs paths. OnRobot*

Another approach that could be adopted is to facilitate access to process programming. Block programming is a visual and guided method of planning the sequence of tasks to be executed by the robot. This methodology allows operators without specific training to generate programs that the robot is capable of interpreting and executing.

[4] *Block-based robot programming with KUKA teach pendants. Source KUKA*

Application

Collaborative and cognitive robotics has a direct application in the furniture manufacturing sector due to the great freedom of movement offered by the 6 axes (standard), the load they can handle (5-10 kg) and their repeatability. At the same time, they offer greater safety for the worker, as they can control it from a certain distance where they are not exposed to dangerous or dirty conditions.

Some tasks in the furniture industry that collaborative robotics can be applied to:

- Wood milling: Robotic milling offers a huge degree of flexibility compared to other forms of milling automation. Strategies such as Looming can bring greater safety and confidence to human-robot interaction. On the other hand, the milling setup can be more operator-friendly if it can be visually programmed.
- Sanding and surface treatment: The great advantage of using robots for sanding is the consistency of the surface finish they provide. Collaborative robotics allows the robot's path to be programmed by teaching and the robot will move the abrasive media over the surface of the material in the same way every time.

These tasks can be performed more efficiently with automatic toolpath generation processes that traverse the surface of the part by entering the CAD of the part.

[9] *Dobot-Robots CR5 robot equipped with a sanding head performs adaptive surface sanding using constant force control. Source: Dobot-Robots.*

• Painting and coating: Painting robots are a perfect option to improve the efficiency of your furniture painting task. Similar to the sanding task, the robot's trajectory for painting can be automatically generated from the CAD of the surface to be painted.

[10] *Universal Robots collaborative robot performing a powder coating task on a metal structure. Source: Universal Robots*

• Assembly of components: Cobots can assist with holding, aligning, or driving fasteners. In practice, cobots may handle repetitive steps (e.g. dowel insertion, hinge fitting) while humans perform fine adjustments. Advanced planning frameworks show promise for mixed human-robot assembly lines in furniture factories. Through voice guidance based on sequential commands in natural language, the efficiency and ergonomics of furniture assembly could be improved.

[11] *Omron cobot with integrated vision system for automatic quality inspection, primarily focused on anomaly detection. Source: Omron website, UNIKA Use Case.*

• Inspection: Robots can be integrated with vision systems, ultrasound scanners and other sensors. This speeds up the furniture inspection process.

• Dimensional scaling: A great advantage of using robots for furniture manufacturing is their large workspace. You can increase the size of the workspace of almost any robot by simply adding external axes. This is very useful when working with large pieces of furniture, making it easier to scale up in size and thus reduces times compared to other forms of automation.

• Palletising: There are already palletising solutions in which humans and collaborative robots interact, providing greater safety and precision in pick & place. Visual markers projected onto the work area give the operator greater confidence and safety.

[12] *KUKA Robot with arm for wood material handling*

Implementation Aspects

■ Implementation difficulty: Low

The ecosystem of most collaborative robots is designed for quick and easy deployment. Since these robots are generally small, they are often fixed to the workbenches themselves. The controller of the robot is also usually small in size compared to industrial controllers. Most manufacturers provide access to tutorials for self-learn-ing, but they also provide training in commissioning. The programming environment of a collaborative robot to perform simple operations, e.g. movements and pick & place actions, is very user-friendly.

In addition, collaborative robots are programmed in a standard way by demonstration, moving the robot by hand to the points of interest. The robot then repeats the movements. Above all, most have graphical programming systems, which move away from traditional text-based programming and simplify the process.

Most collaborative robots have a hardware/software ecosystem similar to an app store for mobile phones. You buy a particular piece of hardware (e.g. a gripper), mount it on the robot, download software from a repository and install it directly and the robot is ready to work. You don't need to configure anything; the system does it automatically.

■ Economic viability: Medium-High

The economic viability of implementing collaborative robots in the furniture manufacturing industry is medium-high, due to their balance between initial cost and operational benefits. With prices ranging from €25,000 to €50,000, cobots can automate repetitive tasks without the need to dedicate safety resources (safety cages, active safety elements, etc.) exclusively to their operation, improving productivity and reducing work-related injuries. Their ease of programming and flexibility to adapt to different processes makes them profitable in the medium term, especially in variable or customised production environments.

An industrial robot is considered to cost 33% for the robot + 33% for peripherals and additional elements + 33% for programming and commissioning. A collaborative robot can reduce the need for peripherals and programming. A reduction of 27.5% is estimated when using collaborative robotics.

■ Human factors

The integration of collaborative robots (cobots) in furniture manufacturing significantly reshapes how human workers interact with technology, tasks, and each other. Although cobots are designed to operate safely near humans, initial worker hesitation is common, often stemming from unfamiliarity, perceived risks, or concern over job displacement. Addressing these concerns requires transparent communication, hands-on demonstrations, and a clear articulation of how cobots support (not replace) human roles. From a psychological standpoint, cobots must be perceived as helpful teammates rather than intrusive machines. Workers who feel involved in their deployment and can influence how cobots are integrated are more likely to accept and adopt the technology.

Trust is fostered through consistent cobot behaviour, clear feedback (e.g., visual or auditory signals), and well-defined safety zones. Importantly, cobots must comply with safety regulations such as ISO 10218 and ISO/TS 15066, which define requirements for safe physical interaction and force limitations in human-robot collaboration. Regular interaction and gradual task handovers help workers build familiarity and confidence over time.

Operators must be trained not only in the technical aspects of programming and supervising cobots, but also in collaborative task planning and basic troubleshooting. Modern cobots often use user-friendly, low-code interfaces or gesture-based programming, which shortens the learning curve, if guided properly.

By offloading physically intensive or repetitive tasks, cobots reduce fatigue, prevent musculoskeletal injuries, and enable older or less physically able workers to remain active contributors. However, these ergonomic benefits must be reinforced by proper workstation design. Collaborative environments should be co-designed with input from operators to ensure comfort, task flow, and visibility. Poorly planned layouts can create confusion or safety issues.

Ultimately, cobots are most successful when seen not as replacements, but as enablers of a more balanced, safer, and more fulfilling work environment.

■ Environmental factors

The implementation of collaborative robots (cobots) in the furniture manufacturing industry raises important environmental considerations both at the workspace level and across the product life cycle. In terms of immediate working conditions, physical space is a critical factor: cobots require sufficient clearance for safe human interaction, access to tools, and materials. Compact and flexible mounting solutions (floor, table, ceiling) help optimise layouts in space-constrained workshops. Lighting and visibility also play a vital role, particularly for cobots using vision systems, where stable lighting improves accuracy and reduces material waste from inspection errors or rework. Dust from wood processing, along with high humidity or temperature, may affect sensors and joints, requiring protection or preventive maintenance.

From a life-cycle perspective, the environmental impacts of cobots span several stages. Material extraction for metals (e.g., aluminum, steel) and rare earth elements (e.g., neodymium) carries a high ecological footprint. The manufacturing phase is energy-intensive, while in the use phase, cobots can improve resource efficiency by reducing waste and enabling just-in-time workflows. However, AI-driven robotics often depend on data centers and cloud infrastructures that also consume significant energy and water. Moreover, cobots eventually contribute to e-waste; their complex mechatronic design can complicate disassembly and recycling.

On the positive side, the integration of AI-powered cognitive robotics enables more precise motion planning and adaptive behaviour, which minimises unnecessary movements, reduces energy consumption, and improves material utilisation. For truly sustainable deployment, advances in energy-efficient processors, neuromorphic chips, and edge AI optimisation are essential to lower the environmental footprint of intelligent robotic systems.

■ Alignment with certifications and regulations

Collaborative robotics is mainly regulated by ISO 10218-1/2 and ISO/TS 15066, which establish safety requirements for industrial and collaborative robots. ISO 10218 defines general guidelines for safe design and operation, while ISO/TS 15066 complements these requirements for collaborative applications by specifying limits of force, pressure and safe robot-person contact.

The installation of the collaborative robot requires global certification, including the robot, the tools and the software. There are companies that specialise in certifying the use of cobots according to current standards, taking physical measurements and checking that the permitted limits are not exceeded.

Human-Robot Interaction (HRI) in furniture industry

Solutions

Automated Sanding Cell
Mirka + Universal Robots
Finland / Denmark ⊖

A flexible cobot-based sanding solution designed for surface finishing in wood and furniture production. The system seamlessly integrates Mirka's electric sander with Universal Robots' collaborative arms, offering programmable, repeatable movements. It supports quick tool change, adjustable pressure control, and compatibility with various sandpaper types, making it ideal for flat and curved furniture surfaces.

NoCode Interface for robotic assembly programming
YK-Robotics
Italy ⊖

This robotic gluing and dosing solution is optimized for wood and furniture assembly processes. It features a NoCode, object-oriented interface that allows for simple, intuitive, and flexible programming of robotic cells. Both developers and machine operators can create and modify programs without prior coding experience, enabling quick adaptation to new product geometries or adhesives.

Robotic Material Handling for Furniture
Dexterity
United States ⊖

Dexterity offers AI-driven robots for complex material handling tasks like picking, palletizing, and sorting of bulky furniture components. These robots operate safely alongside humans, adapt in real-time to unpredictable environments, and require minimal integration effort. Their dexterous arms and perception systems handle irregular or fragile items with precision.

AI-Driven Robotic Programming
AI-Driven Robotic Programming
Canada ⊖

RoboDK is a powerful offline programming and simulation platform for industrial robots. It allows users to import CAD models, define toolpaths, and generate robot programs without interrupting production. Applications include welding, milling, painting, inspection, and pick-and-place, with AI-enhanced features for path optimization and collision avoidance.

Multisensing Intelligent Robotic Assistant (MAiRA) for Furniture
Neura Robotics
Germany ⊖

MAiRA is an all-in-one cognitive robot that combines computer vision, artificial intelligence, environmental perception, and voice/gesture control. In furniture manufacturing, it handles sanding, drilling, gluing, and inspection tasks, adapting to changing materials and shapes. It enables safe, intuitive human-robot collaboration without fencing, improving quality and flexibility on the shop floor.

AI Accelerator
Universal Robots (with parent company Teradyne Robotics and Mobile Industrial Robots - MiR), partnering with NVIDIA (IsaacTM robotics platform)
United States ⊖

Cobots empowered by AI gain the ability to learn, adapt, and make informed decisions grounded in their sensory input, handling complex tasks like bin-picking varied objects. Cobots better understand their surroundings, plan optimal paths, and execute tasks safely and efficiently. As an example, MiR1200 Pallet Jack can deal with complex warehouse requirements and dynamic environments using LiDAR for fully autonomous navigation.

Spray coating for large-sized objects with cobot and 3D camera
Cefla
Italy ⊖

The iGiotto is an advanced 6-axis anthropomorphic spray-coating robot engineered for finishing large and intricate items such as doors, window frames, and various furniture components. With the optional 2D/3D c-Vision scanner, it can autonomously generate accurate spray paths, eliminating the need for manual programming and cutting setup time by up to 50%. Its in-line spraying capability enables real-time control, including slowing or pausing the conveyor when necessary.

Examples

Alnea
Poland

Boxing furniture pieces in flat pack case: Alnea's robotic furniture packaging system uses advanced vision for intelligent picking and trajectory control. The cobot integrates AI-driven image recognition to locate parts, adapt to their positions, and plan collision-free paths in real time. This ensures efficient, damage-free packaging of diverse furniture components, especially in variable production lines.

Techman Robots
Taiwan

Cognitive Cobot for Sanding: Techman Robots' collaborative sanding application combines AI, vision systems, and force control to adapt to different furniture surfaces. These cobots identify object shapes, adjust sanding pressure dynamically, and execute precise trajectories. Their built-in smart vision makes them ideal for automated wood finishing tasks in furniture production.

Pickle Robot
United States

AI-powered robotic depalletizing: Pickle Robot offers AI-powered robotic depalletizing for unstructured loads such as furniture boxes. The system uses real-time perception to identify, grasp, and move mixed items efficiently. With no need for predefined layouts, it enables flexible and autonomous unloading, optimizing labor and operational flow in furniture logistics.

CMA Robotics
Italy

Automated wood finishing: CMA Robotics has implemented advanced robotic systems for the automated painting of wooden furniture components, including chairs, tables, and panels. These systems utilize 3D vision technology to accurately identify and paint various shapes, enhancing finish quality and production efficiency in the furniture industry.

Medienos Era
Lithuania

Custom packaging automation: Medienos Era, a Lithuanian solid wood furniture manufacturer, implemented the RoboCut solution developed by Industrial Robotics Company. This robotic system enables in-house production of custom cardboard packaging, reducing waste and improving logistics efficiency. The technology ensures consistent quality and greater flexibility in handling varied product dimensions.

Becker Romania (subsidiary of the German company Becker Brakel)
Romania

Assembly tasks: adoption of two collaborative robots (UR10) working in tandem to handle glue dispensing and pick and place tasks in the manufacturing line of molded wood, with human operators working alongside the two collaborative robots. The setup is controlled by the teach pendant and the predefined program CircleMove has been adopted for programming; application-specific variables have been defined to interact with operators, for example to warn them when adhesive need to be changed

Industrial Robotics
Lithuania

Robotic Carpenter: The Wood Component Manufacturing solution by Industrial Robotics uses a 6-axis RoboMill cell equipped with automatic tool changers for drilling, milling, routing, and riveting. This flexible robotic system handles complex wooden frame parts. Its programmable setup allows for small-batch production and varied geometries, reducing reliance on skilled labor. When CAD/CAM projects are created, the operator simply needs to enter the order number and quantity, load the blanks onto the conveyor, and initiate the system. The robotic carpenter then autonomously executes the tasks.

**Extended Reality in product design
and prototyping processes**

2

Implementation difficulty: **Medium**
Economic viability: **Medium-High**

Extended Reality in product design and prototyping processes

Description

Extended Reality (XR) encompasses the full spectrum of immersive technologies, including Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR). In the context of furniture design and prototyping, XR technology enables interaction with digital three-dimensional models in both virtual and physical environments, providing a highly realistic experience. This technology relies on the integration of specialized hardware (headsets, controllers, sensors) and software to create simulated environments or overlay digital information onto real-world settings.

XR represents a paradigm shift. Prior to its emergence, the design of three-dimensional objects such as furniture was always conducted through flat interfaces—whether paper and pencil or mouse and screen. Now, it is possible to design furniture directly in three dimensions, instantly and accurately verifying dimensions, functionality, and ergonomics.

During the conceptualization phase, XR allows designers to visualize a full-scale prototype with great fidelity, assessing its ergonomics, aesthetics, and functionality before proceeding to physical production. It also enables quick iteration of multiple design variants, reducing costs and shortening development timelines. Users can virtually walk around a chair model, check its proportions, or even simulate sitting down to test the comfort of the shape.

On the other hand, Augmented Reality enables interaction with virtual objects in the physical space. In custom furniture design, clients can use a mobile device or AR glasses to select finishes, colors, or dimensions while viewing the piece overlaid in their own environment. This elevates the level of co-creation, as the client actively participates in the design and prototyping process, adjusting parameters in real time and immediately visualizing the outcome.

XR naturally integrates with other digital enablers, such as digital twins or the Internet of Things (IoT). For instance, sensor data (materials, stress, resistance) can be obtained and visualized in real time on an immersive 3D model. This supports data-driven decision-making, minimizes errors, and promotes sustainability by avoiding the need for physical prototypes in multiple iterations.

Ultimately, Extended Reality delivers tangible benefits to the furniture industry: faster and more accurate prototypes, greater product customization based on client preferences, and a highly flexible and collaborative design process. All of this results in reduced waste, shorter development times, and a more satisfying end-user experience. XR, through its immersive and virtual manipulation capabilities, is a key tool in the digital transformation of the furniture industry, driving it toward business models centered on innovation, efficiency, and environmental responsibility.

Application

Extended Reality has a decisive impact on the furniture design and prototyping process by offering an immersive platform for quickly visualizing, iterating, and validating ideas without relying solely on physical prototypes. Its greatest value lies in the ability to recreate virtual workspaces where design teams, clients, and other stakeholders can examine a highly detailed and realistic 3D model.

First, immersive simulations using VR allow for effective evaluation of formal and aesthetic features. Furniture comes to life in a full-scale virtual space, offering perspectives that are impossible to achieve with traditional 2D drawings. This enables early adjustments to ergo-

nomics or dimensions without consuming materials or resources on physical prototypes.

XR also enables direct co-creation with clients. Using AR, a digital prototype can be overlaid in the user's environment—such as a living room or office—where colors, textures, or structural configurations can be modified. In this way, the client actively defines the product, instantly seeing changes and evaluating how well it fits the aesthetics and available space. This dynamic increases satisfaction while reducing returns and production errors. Other features, such as physical feedback, differences in the physical textures of materials, and even the smells of wood and other materials remain a problem to be solved to achieve the most complete immersion and address more decision factors that are not necessarily objective from an engineering perspective, and more related to emotional perceptions.

Another key application is functional validation in early stages. The virtual prototype can undergo simulated "use tests" to analyze its behavior under different load, stress, or movement conditions. When integrated with data analysis and sensor tools (digital twins), more precise readings are obtained for structural testing, improving the final design's quality and safety.

Collaboration is another critical factor. Engineers, designers, and suppliers can simultaneously connect to a shared VR environment to discuss and revise aspects of the prototype in real time, regardless of location. This fluid communication ultimately streamlines decision-making, avoids misunderstandings, and fosters collective creativity.

Finally, XR significantly impacts resource optimization in product innovation processes by minimizing the need for multiple physical prototypes. While traditional physical prototyping costs $2,000-$15,000 per furniture piece iteration, XR implementation reduces this by 60-80%, with payback period typically 8-12 months for mid-size furniture companies. Development time reduction averages 30-50% based on industry case studies. Each virtual iteration is a concrete step toward the final version, with reduced material use, which not only supports environmental sustainability but also eases economic pressure during the initial phases of furniture design.

Implementation Aspects

Implementation difficulty: Medium

Adopting XR for design and prototyping requires initial investment in equipment (headsets, specialized software) and staff training. While the technology is mature, integrating it into daily business routines may entail organizational and cultural changes. Workflow updates and coordination among multidisciplinary teams (designers, engineers, developers) are necessary. However, the learning curve flattens over time: basic VR proficiency can typically be achieved in 2 to 3 weeks, advanced design workflows in 2 to 3 months, and full team integration in 4 to 6 months, with a training cost around $1,500-$3,000 per designer. Commercial solutions typically offer comprehensive support and best practices suited to SMEs.

Economic viability: Medium-High

Despite the investment in hardware and training, the reduction in errors and physical prototypes quickly justifies the expense. By shortening development cycles and enabling greater customization, companies can optimize inventories, cut rework costs, and respond swiftly to client demands. The added value of interactive experiences accelerates decision-making and improves customer satisfaction. In the medium term, ROI is reinforced by more targeted sales and reduced waste.

Human factors

The integration of XR technologies into design and prototyping processes significantly affects how work teams in the furniture industry collaborate and operate. First, successful adoption depends on continuous training and digital upskilling: designers, engineers, and plant operators must acquire the competencies needed to operate immersive devices confidently and effectively. This learning curve helps reduce resistance, builds confidence, and enables more fluid integration of XR tools into daily innovation routines.

In addition, VR and AR foster greater collaboration by providing a shared, visual, and interactive language. This reduces communication barriers between departments, aligning teams around visual prototypes and real-time feedback. As a result, workers become more engaged and feel ownership of the creative process, seeing their input materialize directly in the virtual environment.

However, XR usage also brings ergonomic and health considerations. Extended use of immersive environments can lead to eye fatigue, disorientation, or motion sickness—making it essential to define clear usage protocols, like stablishing breaks between XR sessions. It's also important to note motion sickness as a common implementation barrier that affects 15-25% of users

initially. Likewise, AR requires users to manage attention between physical and virtual elements, necessitating specific safety measures to avoid cognitive overload or accidents.

When applied with a human-centred approach, XR can boost learning, engagement, and well-being—provided ergonomic, cognitive, and organisational aspects are properly addressed to ensure a safe and inclusive work environment.

■ Environmental factors

Applying XR in the furniture industry helps reduce material consumption and waste generation, since most testing and validation is carried out virtually. It is no longer necessary to produce physical prototypes for each product iteration or variant, thus lowering the carbon footprint associated with transporting components and disposing of discarded parts.

Moreover, the ability to co-create remotely with clients reduces the need for in-person meetings and physical samples. This translates to fewer emissions and a smaller logistical impact. Additionally, XR-integrated data analysis systems—such as digital twins and simulation tools—enable the design of furniture with eco-design and energy efficiency criteria, optimizing raw material usage and minimizing waste.

On the other hand, from a life-cycle perspective, XR-supporting devices include high impact materials and components (e.g. head-mounted displays (HMDs), sensors, controllers, and sometimes external computers or smartphones), which contain a mix of plastics, metals, rare earth elements (REEs), and complex electronic circuits. These components involve environmentally intensive extraction and manufacturing processes. This environmental burden is exacerbated by the short lifespan of many consumer XR-supporting devices, often replaced within 2–3 years due to rapid technological advancements. In the use phase, power requirements vary by system, but continuous use of high-end HMDs and processing units can lead to significant cumulative energy consumption over time. At end-of-life, XR-supporting devices add to the growing e-waste problem, using components such as lithium batteries, LED displays, and sensors that can be hazardous if not properly handled.

In short, XR could offer a positive environmental balance when implemented consciously, maintaining a global focus on resource savings and sustainable design.

■ Alignment with certifications and regulations

XR projects in furniture design must first align with horizontal management frameworks: ISO 45001 supplies the occupational-health-and-safety system that governs headset ergonomics, session length and general duty of care; the EU's GDPR regulates all personal data collected during immersive sessions, from user accounts to any biometric traces, and demands a Data-Protection-Impact Assessment where eye-tracking or spatial-mapping can reveal sensitive traits; meanwhile ISO 14001 extends the same life-cycle discipline to environmental performance, ensuring that virtual prototyping really offsets the raw-material, energy and e-waste footprint of XR devices.

Building on that baseline, furniture makers should reference ISO/IEC 23053:2022 for the overall XR/AI system architecture and the IEEE 2048 series for device taxonomy, latency, media formats and user-interface safety; together they provide a common language for suppliers and auditors. In the workplace, OSHA's virtual-training guidance treats immersive training as "adequate" only when it demonstrably improves hazard awareness, reinforcing the need for risk reviews before deployment. Finally, hardware shipped into the EU must clear the Radio, EMC and Low-Voltage Directives and carry the CE mark; technical files should document compliance with the above standards.

Extended Reality in product design and prototyping processes

Solutions

VR Sketch
Baroque Software
Multinational ⊖

Collaborative VR plugin for SketchUp that allows multiple users to design and edit 3D models in an immersive environment. It speeds up validation and reduces design errors by providing real-time, full-scale visualization. Aimed at joint work between engineers and creatives.

Gravity Sketch
Gravity Sketch Group
United Kingdom ⊖

Professional software focused on immersive 3D modeling. It integrates NURBS curves and intuitive tools in VR or AR environments, enabling real-time co-creation. Used in the furniture industry to generate prototypes and validate complex geometries before final manufacturing.

Enhance
Enhance XR
Spain ⊖

Platform for developing furniture e-commerce solutions using 3D and AR technology. It allows users to interactively customize furniture in real time.

Moblo
MYTIforge
France ⊖

Cross-platform software designed to generate basic furniture models for VR and AR viewing (mobile only). It allows basic modeling from editable blocks as well as the generation of material libraries. Its interface is simple and agile but lacks multi-user capabilities.

ShapesXR
ShapesXR Inc.
Denmark ⊖

Collaborative VR design platform enabling multidisciplinary teams to create and iterate furniture prototypes in real-time. Features specialized ergonomic measurement tools, material stress analysis capabilities, and biomechanical simulation. Compatible with multiple VR headsets (Meta Quest, HTC Vive, Pico) and offers direct export to manufacturing software including CNC programming and 3D printing preparation.

Examples

Bakken & Bæck
Norway

Technocarpenter – Sculpting Furniture in VR: An experimental project that uses AI and natural gestures in a VR environment to sculpt unique furniture. Users shape their ideas with hand movements, which the system translates into 3D models ready for printing or manufacturing, encouraging co-creation and innovation

Paolo de Jesus y XR+
Germany-France

Thinking Woman's Chair: An initiative by the WORTH Partnership Project proposing a rocking chair designed for CNC manufacturing. It includes AR-based instructions that guide users through assembly. The immersive experience promotes engagement and customization, offering a more human and creative approach to furniture development

Damiano Latini & Nicholas Baker
Italy

This company has adopted VR in its conceptual design and prototyping process. A standout case is the "Super Chair," developed with designer Nicholas Baker, fully modeled in 3D using VR before any physical prototype was created.

Matt Antes & Cullan Kerner
United States

Chair1: A prototype chair made from recycled PETG, designed in VR to enable fast prototyping and virtual adjustments before sustainable manufacturing via industrial 3D printing. Designed using Gravity Sketch.

UMAGE ApS
Denmark

Umage Augmented Reality: AR application for co-creation and virtual interior prototyping. Their website features an AR function that allows users to view UMAGE's lamps and furniture at real scale in their own homes before purchasing.

Roche Bobois
France

Mah Jong 3D: mobile app enables users to digitally create and customize a Mah Jong sofa composition, choosing module configurations and applying various fabrics (including Jean Paul Gaultier, Kenzo Takada, Missoni, etc.), then visualizing the result in 3D and AR.

IKEA
Sweden

In 2017 IKEA launches IKEA Place that makes it easier to make buying decisions in your own place, to get inspired and try many different products, styles and colours in real-life settings with a swipe of your finger on your Apple device.

Natuzzi Italia
Italy

Natuzzi Augmented Store: Italy's largest furniture manufacturer has implemented a comprehensive XR solution called "Augmented Store" in collaboration with Microsoft and Hevolus Innovation. Using Microsoft HoloLens 2, customers enter a digitally rendered version of their own home in VR to visualize and customize Natuzzi furniture pieces. The augmented store concept combines VR immersion with AR home visualization and has been rolled out to over 1,000 Natuzzi locations globally.

Leveraging extended reality for workforce training and upskilling in the furniture industry

3

Implementation difficulty: **Medium**
Economic viability: **High**

Leveraging extended reality for workforce training and upskilling in the furniture industry

Description

Extended Reality (XR) encompasses a set of immersive technologies that merge the physical and digital worlds. It includes three main branches: Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), each offering varying degrees of immersion and interaction.

Virtual Reality (VR)

Virtual Reality fully immerses users in a three-dimensional digital environment through the use of dedicated headsets or glasses. This technology is particularly suitable for simulating woodworking workshops or furniture production lines, enabling the acquisition of complex skills in a safe and controlled setting. Operators can rehearse specific movements, handle virtual tools, and follow step-by-step procedures without physical risks or material waste. Interaction within the simulated environment allows for the replication of real-life exercises, including performance evaluation based on successes and errors. VR-based training proves valuable both for initial instruction and for upskilling or reskilling in mechanical or automated processes. Industry studies have shown that VR training significantly enhances knowledge retention (up to 80%) and accelerates skill acquisition compared to traditional methods. Moreover, it enables the recording of progress metrics, identification of common mistakes, and adaptation of training content to the individual learning pace of each worker. [1]

Augmented Reality (AR)

Augmented Reality overlays digital information onto the real-world environment, accessible through transparent smart glasses or mobile devices. It is particularly valuable in assembly, maintenance, and quality control processes, where real-time precision is essential. Step-by-step instructions can be projected directly onto furniture components or machinery, guiding the operator through tasks with contextual cues. Thanks to integrated cameras, trainers or technical experts can provide remote assistance by viewing the worker's field of vision and sending synchronised visual support. AR also enables interaction with anchored 3D models within the physical workspace, improving the understanding of structures, components, or operational sequences. Furthermore, it facilitates on-the-job self-training, as instructional resources can be accessed directly in the working environment without interrupting production activities. Moreover, AR allows easy and rapid updates of instructional content digitally, reducing the need for printed manuals and enabling faster dissemination of process changes [2]

Mixed Reality (MR)

Mixed Reality represents an advanced convergence of VR and AR, enabling interactive virtual objects to be integrated into the physical environment in real time. Unlike VR, MR does not isolate the user but instead enhances the surrounding environment with contextual digital content. It is used through two main types of devices: transparent optical headsets (e.g. HoloLens) and opaque headsets equipped with external cameras (e.g. Meta Quest 3, Apple Vision Pro). MR enables operators to work with real machinery while receiving virtual instructions overlaid in their field of vision. Guidance may include highlighting specific areas, displaying assembly schematics, or issuing visual safety alerts. In design and supervisory contexts, MR allows for prototype validation, dimensional verification, and real-time collaborative review without interrupting production workflows. The choice of headset depends on the required level of detail and the nature of the task, ranging from lightweight supervision to advanced technical simulation. MR also enhances remote collaboration, enabling multiple users to interact with the same digital model from different locations simultaneously.

Collectively, these three technologies offer a broad spectrum of training solutions adaptable to various professional profiles within the furniture industry (from shop floor operators to technical designers) with a strong impact on efficiency, safety, and the standardisation of processes. [3]

Leveraging extended reality for workforce training and upskilling in the furniture industry

Application

The furniture industry, characterised by highly manual processes and specialised craftsmanship, is increasingly adopting Extended Reality (XR) technologies as key tools for workforce training and the continuous development of technical skills.

Virtual Reality (VR) enables the simulation of real working environments such as carpentry workshops, assembly lines, or CNC machinery setups without requiring physical materials. Using VR headsets, workers can practice complex tasks such as furniture assembly, the use of power tools, or the programming of automated machinery in a fully immersive and safe environment. This reduces occupational hazards. Companies adopting VR training have reported reductions in workplace injuries of up to 70%, as workers can safely practice high-risk operations virtually. It also minimises resource consumption, and shortens learning curves.

Augmented Reality (AR) proves particularly effective in assembly and maintenance tasks. Through transparent smart glasses or mobile devices, workers can visualise step-by-step instructions overlaid directly onto physical components. This facilitates real-time learning without the need for constant supervision and increases accuracy in repetitive or high-precision operations. In the furniture sector, this is especially applicable to the assembly of complex structures, quality control procedures, and customised adjustments.

Mixed Reality (MR) goes one step further by allowing virtual elements to interact with the physical environment. For example, a trainee can view a 3D model of a furniture item projected onto a real surface, manipulate it virtually, and gain a better understanding of its structure before physical construction. Additionally, video-based MR (Video See-Through) can simulate entire operational scenarios, such as managing a production line, enabling direct interaction between real and digital environments.

These technologies can be particularly effective in the following processes:

- Training in the use of CNC machinery and specialised tools.
- Assembly and installation of modular components.
- Quality control supported by guided instructions.
- Product design and personalisation for on-demand manufacturing.

Industrial designers can leverage VR to rapidly iterate on 3D prototypes, assessing proportions, materials, and functionalities of furniture products in immersive environments, thus avoiding the need for physical mock-ups. This advanced visualisation also supports collaborative model review before technical validation. [4]

In the plant environment, instructors can use AR to standardise procedures by projecting visual instructions directly onto the workstation, ensuring consistent, hands-on training for assembly, cutting, or machining tasks. This is particularly beneficial for onboarding new workers or managing internal staff rotations, allowing operators to follow each step directly over the real components. [5]

Meanwhile, MR is especially advantageous for intermediate technical profiles and production managers. These professionals can interact with digital models of assembly lines, identify bottlenecks, or suggest process improvements without disrupting actual operations. MR can also be used to validate customised product configurations prior to physical assembly. [6]

Implementation Aspects

Implementation difficulty: Medium

The integration of XR in the furniture industry is feasible, though it requires investment in hardware, software, and employee training. VR for worker training is relatively easy to adopt using existing market solutions, becoming more complex when tailored, non-generic solutions specific to individual companies are required. MR and AR may present higher implementation challenges than VR due to the need for real-world environment synchronization. The resources dedicated to preparing assets and simulations must be considered so that the systems are profitable in the medium term. As with any economy of scale, the impact of these developments and methodological updates on operations is one of the greatest risk factors when adopting new tools, whether physical or digital.

Economic viability: High

The use of XR in the furniture sector can significantly reduce design and production costs, minimise errors, and prevent workplace accidents. Companies that adopt MR, AR, and VR for training and upskilling can achieve substantial process efficiency gains, which can justify the initial investment (especially for companies with high production volumes and workforce turnover). The cost of certain devices is relatively low, and implementation is straightforward using existing off-the-shelf solutions.

■ **Human factors**

The adoption of Augmented and Virtual Reality (AR/VR) in the furniture industry introduces a set of critical human factors that influence successful implementation.

One major consideration is the user learning curve linked to immersive technologies, particularly for workers unfamiliar with head-mounted displays (HMDs), spatial navigation, or gesture-based interaction. Without sufficient training and exposure, employees may feel disoriented or resistant to engaging with virtual environments.

Discomfort, fatigue, or cybersickness—especially in VR settings—can pose challenges to prolonged use, particularly if ergonomics or calibration are not properly addressed. This underscores the need for high-quality, ergonomically designed hardware and personalised usage protocols (e.g. session length, seating posture, visual adjustments).

Worker engagement is another central factor. If employees perceive AR/VR as detached from real operational needs or as just another "tech experiment," their motivation to adopt it may decline. Conversely, when workers are involved early — for example, in content creation or scenario testing — their buy-in increases significantly.

Trust in virtual content is also crucial. Inaccurate or poorly contextualised simulations reduce trust and may lead workers to revert to traditional methods. Maintaining high fidelity in visuals and interaction improves not only immersion, but also user confidence in the value of the technology.

Moreover, AR/VR solutions should be inclusive. Solutions must consider varying physical and cognitive capabilities among users, such as those with visual impairments or reduced dexterity. This includes adjusting font size, interface complexity, and interaction modes (e.g., voice vs. hand control).

Finally, AR/VR implementation requires a cultural shift. Encouraging experimentation, creating digital sandboxes for practice, and promoting peer learning helps reduce anxiety and boost confidence. Managers play a key role by framing immersive tools as job aids rather than performance surveillance systems. With a human-centered design and rollout strategy, AR/VR technologies can become powerful enablers of worker empowerment, operational learning and health-conscious environments.

■ **Environmental factors**

The adoption of XR technologies for training, upskilling, and reskilling in the furniture industry can contribute significantly to environmental sustainability, provided it is implemented from a responsible-use perspective. One of the main environmental advantages of XR in industrial learning lies in its ability to replace the intensive use of physical materials with immersive virtual environments. Workers can train in design, prototyping, assembly, or maintenance tasks without consuming real resources such as wood, hardware, adhesives, or coatings. Through interactive simulations, errors can be made, processes repeated, and multiple scenarios evaluated without generating waste or depleting raw materials.

The use of XR in technical training also enables better planning of plant and workshop operations, optimising workflows and the use of machinery, tools, and production spaces. This can reduce unnecessary travel, minimise energy consumption, and decrease emissions resulting from logistical or decentralised in-person training activities, which often involve travel between sites or on-site interventions by specialised technical staff.

It is also important to consider the environmental footprint of the infrastructure required for XR solutions. The production and maintenance of headsets, sensors, controllers, and servers involve plastic, metals and electronic materials with high environmental impact (i.e. critical raw materials, rare earth elements, etc.) and are often difficult to recycle at their end-of-life, contributing to a non-negligible ecological impact. Additionally, intensive graphic processing and continuous data transfer may lead to increased energy consumption during use if not managed through efficient resource strategies. Also cloud-based rendering, multiplayer environments, real-time data synchronization, and AI-enhanced environments require data center support and edge computing, which are large consumers of electricity and water.

■ **Alignment with certifications and regulations**

XR technologies applied to the furniture sector must align with occupational safety standards such as ISO 45001 by enabling realistic training in hazard identification and risk prevention, ensuring safe working environments even within virtual simulations. These technologies can also support compliance with environmental standards, such as FSC or PEFC certifications, by enabling digital traceability systems and visualisation of material life cycles. Furthermore, XR-based technical training can help reinforce compliance with quality standards and occupational risk prevention regulations.

Leveraging extended reality for workforce training and upskilling in the furniture industry

Solutions

XR Streaming for woodworking
Felder Group
Austria ⊝

Use of XR to train operators in CNC machine handling, reducing the learning curve and improving production efficiency.

SimLab XR Training for Furniture
SimLab Soft
Germany ⊝

VR and AR-based furniture assembly simulator, enabling operators to receive practical training prior to handling physical materials.

VR Carpentry Simulator
UP360
Canada ⊝

Virtual Reality simulator allowing workers to practice carpentry tools and techniques in a safe and controlled environment.

SimSpray VR painter training
VRSim, Inc
United States ⊝

Simspray offers easy-to-use, simulation-based painting & coatings training. teach hvlp, airless, or airassisted airless processes. save time, reduce waste, and accelerate training with immersive vr technology.

Dynamics 365 Guides For Wood Technicians Training
Microsoft
United States ⊝

Mixed Reality application for guiding workers' / students' training and workflow on actual machinery in the work environment. The holographic, three dimensional prompts guide technicians while actually performing their tasks on phisical materials and machinery. Tailor-made, in-house content development is easy and quick; the software is compatible with different XR headsets.

KIT-AR - KIT-Assist & Insight
KIT-AR
Portugal / UK ⊝

A suite of industrial augmented reality tools aimed at providing 3D step-by-step instructions and process analytics.

Simuladores de Realidad Virtual para Formación Profesional
VRFP
Spain ⊝

A simulator designed to teach the correct use of woodworking machinery, with which students learn to identify the parts of a miter saw, a table saw and a band saw, as well as the functions of each of these tools.

Examples

Fologram
Australia

Mixed Reality Carpentry Demonstration: An AR and VR project designed to enhance the assembly of prefabricated components in carpentry and construction. Through the Twinbuild platform, carpentry apprentices can assemble complex wooden structures using virtual guidance and real-time assistance.

Human Interface Technology Lab (HITLab)-Howest University of Applied Sciences
Belgium

Woodcraft VR is an educational virtual reality application available for Meta Quest, where users can learn basic carpentry techniques and virtually work with hand tools in a simulated workshop.

Innoarea Projects S.L
Spain

VR is a virtual reality project developed to train professionals in the wood and furniture sector on the use of specific machinery. It enables the simulation of industrial environments safely and enhances technical training through immersive scenarios.

SCM Group
Italy

SCM Maestro Smartech AR is an augmented-reality wireless device allows their technicians to assist the client efficiently, even remotely, employing: live POV video streaming to remote technicians; hands-<free data visualization and interaction; two-ways sharing of blueprints, schematics, and checklists; real-time annotations, text & voice communication from remote team. ▶

Artwood Academy
Italy

Mixed Reality Training For Wood Machining Students In ArtwoodAcademy. An MR project, developed with Dynamics 365 Guides and Hololens2, for on-field training in the use of woodworking machinery, such as CNCs and edgebanders. By following video, textual, 3D holographic instructions, the technicians are able to use the machinery in real time: prompts and instructions guide the students in performing standard procedures, ordinary maintenance, and troubleshooting. ▶

JYSK
Denmark

In 2023, furniture retailer JYSK launched "The Right Sales Attitude," a realistic WebVR-based virtual training tool that immerses store staff in interactive, gamified customer scenarios to enhance sales and customer service skills.

CETEM-EU
Spain

XR4Crafts. Development of training material using XR extended reality together with haptic gloves to simulate manufacturing and construction processes such as: carpentry, wall painting, roof construction and installation of floating floorboards.

**Smart functionalities applied
to the furniture sector**

Implementation difficulty: **Medium**
Economic viability: **Medium-High**

Smart functionalities applied to the furniture sector

Description

Smart materials, also known as intelligent or responsive materials, are engineered solutions whose properties can change in a controlled way when exposed to external stimuli such as mechanical stress, pressure, moisture, electric or magnetic fields, light, temperature, or specific chemicals.

In furniture and design, they enhance functionality and adaptability, improving performance and supporting sustainable solutions.

These materials can be categorized into three main groups based on structural and operational features, each contributing distinct advantages to the evolution of furniture.

The first group of smart materials are those obtained by **engineered structures**. This category encompasses all those materials with "intelligent" structures that are designed to better react to mechanical stresses, for example in textiles, foams, or composites; or to light, such as in manipulated surfaces via laser engraving of molds in order to control light reflection and transmission. Other examples include textile structures for seats; engineered foams (memory, draining, etc.) and other padding solutions; and all **metamaterials**, artificially engineered materials designed to have properties that come from their internal structure rather than their chemical composition. Metamaterials can be obtained via 3D printed structures, with the purpose of reinforcement, weight reduction and replacing foamed padding materials.

A second category is that of **conductive materials**. These can feature embedded or printed circuits that facilitate the integration of furniture into the broader smart home infrastructure. By embedding conductive inks, films, or circuit boards, furniture pieces can serve as interactive components, acting as control interfaces, charging stations, or data acquisition nodes, enhancing user convenience and engagement within a technologically integrated household environment. For example, office tables and countertops can be transformed into control surfaces by integrating conductive properties into typically non-capacitive materials like wood or ceramic slabs.

Conductivity also helps create an "infrastructure" for sensors and actuators, providing a dynamic response to touch, such as haptic feedback, allowing furniture to respond to inputs offering tactile sensations that can enhance experiences in virtual reality or relaxation scenarios.

Finally, the broader group of **functional coatings and additives** has perhaps the most interesting features for the furniture industry. They range from truly smart materials that have an active and reversible response to external stimuli, such as phase change materials to materials exhibiting passive functionalities with added -value such as anti-fingerprint surfaces.

These coatings and additives can provide protection, decoration and functional enhancement to the substrates and offer a range of interesting characteristics such as hydrophobicity, stain protection, scratch resistance, anti static, thermochromic behaviour, photoluminescence, self-healing properties, light and temperature control, anti-bacterial, soft touch, colour, special aesthetic effects and many more.

Additives are commonly incorporated during the formulation process to improve material properties. Smart additives can contribute to advanced features such as temperature regulation and quick drying. Phase change materials (PCMs), for instance, regulate temperature in upholstery and bedding by reversibly changing states to absorb and release heat, preventing overheating. Activated carbon integrated into fabrics provides odor absorption and quick drying. Nanotechnology enhances the surface area of activated carbon, facilitating rapid moisture dispersion and evaporation.

Coatings are applied to the material's surface, where they adhere to the substrate. Frequently coatings can provide both functional and aesthetic benefits to surfaces. For example, a coating may provide a hydrophobic, ultra-matte, soft-touch finish, and self-healing capabilities for microscratches.

1 *Flexible electronics that enable the functionalization (soft switches, sensors) of fabric, leather, veneer surfaces - manufacturer: Loomia* ⊝

2 *Illustration of potential features of a smart touch surface (image Materially)*

3 *Thermochromic pigments and dyes by Olikrom* ⊝

4 *Phase Change Polyurethane Foam Thermofresh by Pelma* ⊝

5 *Pollutant absorbing fabric system theBreath®* ⊝

Smart functionalities applied to the furniture sector

Application

The practical applications of smart materials in furniture design span a wide range of domains, offering innovative solutions that enhance functionality, comfort, aesthetics, and sustainability.

In **seating**, **upholstery**, and **bedding**, smart materials are primarily used to improve comfort and ergonomics. These materials are designed to support the body and redistribute weight efficiently, or to reduce the need for conventional padding. In the bedding sector, temperature-regulating foams that incorporate phase-change materials are used in mattresses to absorb and release heat and maintain an ideal sleeping temperature.

Not yet widely available but promising for the future is the development of **smart acoustic absorbers**. These innovative materials will be able to adjust their absorption properties dynamically in response to the surrounding sound environment and could potentially contribute to the creation of a smart acoustic interior.

Another aspect of overall well-being in interiors is related to **indoor air quality**. Multilayer products with a sandwich structure contain hidden interior elements that trap pollutants from heating systems or chemical products. The versatility of these products allow them to be applied in commercial and residential buildings and to contribute to a healthier habitat. They are designed to combine functional elements with a decorative, customizable surface and are suitable to be used as room dividers, curtains and furniture covering. Smart materials are also used to enhance **interaction** and **connectivity** at home, in offices, retail and public environments. Multifunctional, sensor-integrated surfaces are applied to table and kitchen tops to offer intuitive, touch-sensitive controls for lighting and multimedia, seamlessly blending technology into everyday furnishings.

In **retail** furniture, smart shelves embedded with pressure sensors can monitor inventory in real time and adapt lighting or display layouts based on customer movement. In **public spaces**, interactive installations—featuring responsive surfaces or dynamic aesthetics—can engage users in meaningful ways, enriching the environment.

For **outdoor** furniture, hydrophobic coatings repel water and stains, making cleaning easier and improving durability—especially important in high-traffic or exposed environments. In **kitchen** furniture, hydrophobic and oleophobic finishes not only simplify maintenance but also enhance the longevity of surfaces, reducing upkeep costs.

In **lighting** design, structurally engineered transparent smart surfaces can modulate light transmission, reduce glare, and dynamically adapt to different lighting needs for both residential and commercial applications.

From an **aesthetic** standpoint, smart materials offer both beauty and functionality. Anti-fingerprint coatings maintain clarity on glossy or metallic finishes, while micro- or nano-structured surfaces can create color-shifting effects that turn static furniture into visually dynamic pieces.

Sustainability is also a key point. By enhancing durability and reducing the need for replacements, smart materials help lower environmental impact. Self-healing polymers, for instance, can autonomously repair scratches, cracks, or minor tears, extending the product lifespan and reducing waste. This aligns with circular economy principles and supports more sustainable design practices.

In a more futuristic perspective, **energy-harvesting** workstations featuring piezoelectric materials could convert mechanical energy from typing or movement into electrical power, which can be used to run embedded devices or charge electronics—bringing energy efficiency directly into the workspace.

[6] *Canopy bed where interactive functions related to entertainment, health and well-being are controlled via App (Hi-interiors)* ⊖

[7] *Desk Pad with graphene enriched antibacterial coating (Deskpad ⊖ Secondo Piano by Giulio Iacchetti for Danese Milano, Graphene Coating by Directa Plus)* ⊖

[6] [7]

Implementation Aspects

■ Implementation difficulty: Medium

Integrating smart materials into furniture design demands expertise in material science and engineering. Manufacturers must invest in research and development to fully understand the properties and behaviors of these advanced materials. Adapting production processes, ensuring durability, and maintaining user safety can be challenging. While some solutions are ready for immediate application, others require additional manufacturing steps. Conductive materials, often part of larger systems, need careful integration with IoT and home control technologies to ensure seamless communication and functionality.

■ Economic viability: Medium-High

The costs of incorporating smart materials is usually higher due to research and development expenses and material costs. However, in many cases the price difference in the final product is not that impacting (e.g.: anti-fingerprint, repairable nanosurfaces vs standard laminate). Besides, as technology advances and production scales up, costs are expected to decrease, improving economic feasibility.

Finally, smart solutions such as RFID for logistics can payoff in the long term.

■ Human factors

The integration of smart materials into furniture design significantly impacts both the end-users and the workforce involved in manufacturing.

For users, furniture that adapts to individual needs enhances comfort and ergonomics, leading to improved well-being and satisfaction. Features like self-healing surfaces and easy-to-clean coatings reduce maintenance efforts, contributing to a better user experience.

These features are intuitive, making them seamlessly adoptable by users.

The growing integration of communication technology devices into our daily lives is likely to drive a greater offering of smart, connected furniture and domotic interiors. However, the introduction of embedded electronics and sensors may require support to ensure effective and safe utilization.

When evaluating the integration of smart materials, it is important to recognise that the furniture and upholstery sector is traditionally conservative, and users may resist complexity or changes to their habitual interactions with objects.

Applying user-centred design principles can ease this transition and promote broader acceptance.

Collaboration between designers, engineers, and production staff becomes increasingly important to ensure that the implementation of smart materials aligns with design intentions and manufacturing capabilities.

For workers in the sector, the adoption of smart materials requires upskilling to handle new materials and technologies.

Training programmes should cover technical knowledge and collaborative and safety aspects, fostering a shared understanding between departments.

Additionally, workplace safety protocols may need to be updated to address any new hazards associated with these materials.

Early involvement of workers, the integration of new, more digital profiles and clear communication about the purpose and benefits of smart materials can reduce resistance and increase engagement in the transformation process.

■ Environmental factors

Generally speaking, most smart materials use more scarce materials and are more complex to manufacture, using more energy and resources, often resulting in a higher environmental footprint compared to conventional materials. Due to their intricate composition—such as the use of chemical additives, coatings, or their status as niche materials like shape memory alloys—many smart materials are not currently compatible with established recycling streams. Conductive materials used to integrate electronics are part of complete systems, consisting of multiple components like circuit boards, wires attached to flexible backings, soldered joints, adhesives, stitches, and insulating layers, which makes recycling even more complicated.

Besides, products containing such electrical or electronic components may be classified as WEEE (Waste Electrical and Electronic Equipment) and may need to be separated, treated and disposed of as such.

On the other hand, some smart materials may help reduce the energy consumption and the operational carbon of dwellings, e.g. providing a fresher feeling to mattresses via PCM without the need for air conditioning, but the global balance should be verified.

Conducting a Life Cycle Assessment (LCA) can provide valuable insights into the overall impact of mining, manufacturing, disposal, and energy consumption associated with each specific smart material.

■ Alignment with certifications and regulations

There are currently no specific regulations for smart materials in furniture. However, products must comply with general safety (GPSR), chemical (REACH, RoHS), and electrical directives (LVD, EMC) if electronics are integrated. Standardization bodies like **ISO, CEN, IEC,** and **ASTM** are developing frameworks for smart systems in other sectors, which may extend to furniture. Designers should assess material safety, durability, and environmental impact, and ensure compliance when integrating sensors, lighting, or energy-harvesting functionalities.

Smart functionalities applied to the furniture sector

Solutions

Lattices and Foaming materials (Engineered Structures)
EcoLattice
United Kingdom, India ⊂⊃

Customizable lattice and foam structures which are created through advanced additive manufacturing processes using recycled TPU. Depending on the type of polymer used, these lightweight and breathable structures can be flexible or rigid, hard or soft, and their complex structure can contribute to sound absorption as well. Applications include cushioning, coverings for furnishing accessories and lighting.

Touch surface (Conductive)
Loxone
Austria, Global ⊂⊃

Touch surface is an invisible button that allows to integrate touch control elements directly into hard furnishings and surfaces and can thus transform worktops, tables and other interior and exterior surfaces to become smart elements for controlling home automation functions such as light, sound, shading, heating and cooling.

Customized Smart Textiles (Conductive)
Embro GmbH
Germany ⊂⊃

Custom smart textiles, created using embroidery technology to integrate electrical conductors into textile substrates. Applications include pressure and motion sensors, heating elements, LEDs, and touch interfaces, making the textiles suitable for use in furniture as well as other sectors

Tempotest Home® (Functional coatings and additives)
Parà
Italy ⊂⊃

Furniture fabrics with UV-resistant, hydrophobic finishing that also facilitates the removal of oleous substances. Recently the finishing has been updated and is now free from per- and polyfluoroalkyl substances (PFAS) which are currently under evaluation by the REACH program to be restricted in the EU.

Temperature-Regulating Smart Textiles (Functional coatings and additives
Outlast Technologies GmbH
Germany ⊂⊃

Advanced smart textiles incorporating microencapsulated phase change materials (PCMs) that proactively manage heat and moisture. Originally developed for NASA, this technology absorbs, stores, and releases excess body heat, maintaining a stable microclimate. Studies indicate a potential reduction in sweating by up to 48%, leading to more restful sleep.

Examples

Arper
Italy
🔗

The essential design of the table is further highlighted by Fenix, an ultramatt surface material which covers the table top. The laminate combines a series of features that respond to the visual senses (low light reflectivity, ultramatt appearance), haptics (soft touch) with low maintenance properties (water resistant, anti-fingerprint finishing) and the possibility of thermal healing of superficial micro-scratches.

TPBtech
Australia
🔗

A multifunctional surface which contains an invisible induction cooktop. The highly resistant porcelain-ceramic surface is backed with a heat-dissipating aluminum layer and contains a touch-sensitive control system that is built into the induction cooktop surface. It can be used as a cutting, cooking and plating surface and can become a tabletop too.

Cassina
Italy
🔗

The bed is equipped with wellness supporting materials. Air purification is achieved through the use of the-Breath® fabric, a patented technology that captures and breaks down contaminants to encourage the natural circulation of clean air; while acoustic comfort is obtained through the inclusion of Soundfil® sound-absorbing panels, made of a recycled, hygienic material, capable of diminishing vibrational sound frequencies.

Bauformat
Germany
🔗

The kitchen manufacturer incorporates smart materials such as self-healing surfaces, thermo-reactive laminates, and antimicrobial finishes. These materials respond to stimuli like temperature and humidity, enhancing the durability and hygiene of kitchen furniture. Additionally, they integrate technologies like automated lighting and intelligent storage solutions, optimizing the functionality and efficiency of the culinary space.

**Smartize Product Development Processes with
the adoption of Digital Twin Technologies**

5
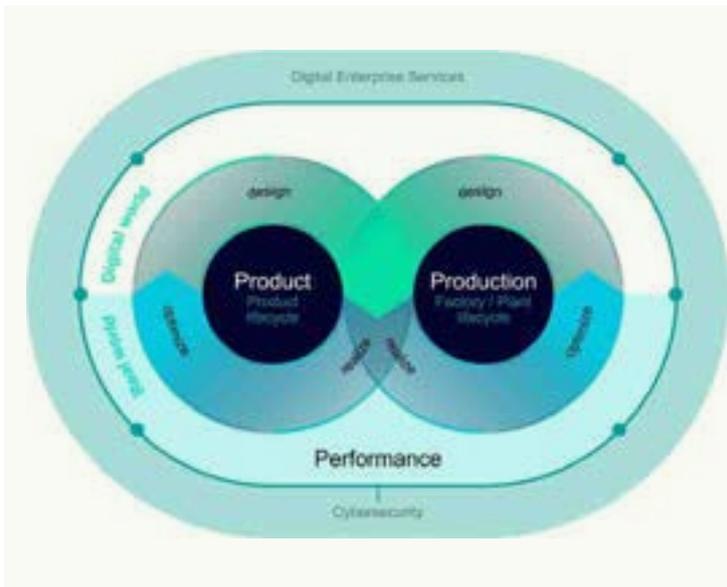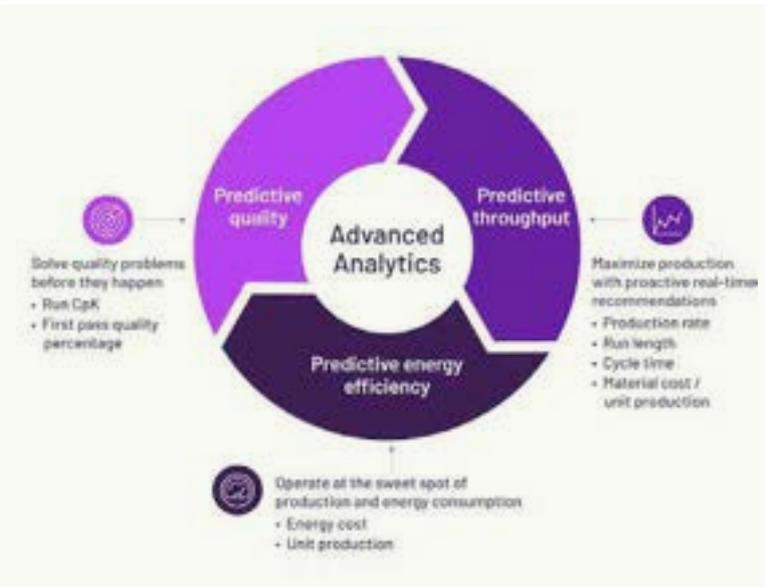
Implementation difficulty: **Medium**
Economic viability: **High**

Smartize Product Development Processes with the adoption of Digital Twin Technologies

📝

Description

Companies live or die by their ability to develop and launch new products. Against this background, companies are seeking to improve their digital-product-development capabilities, seeing these technologies as a way to speed up design and engineering cycles while cutting costs through R&D process optimization.

Digital-product-development approaches are evolving rapidly too, building on advances in computing power, analytics approaches, and artificial intelligence. These have led to the emergence of digital twins (DTs): digital replicas of current or future products that can simulate all the characteristics of their physical counterparts. Interacting with or modifying a product in a virtual space can be quicker, easier, and safer than doing so in the real world.

[1] *Flexible and Efficient Manufacturing (SRC 🔗)*

Product development leaders expect DTs to accelerate product development processes and improve outcomes, all while reducing costs. Implementing DTs in the furniture manufacturing industry **enhance design and prototyping by creating virtual replicas of products**, allowing manufacturers to test and refine designs, reducing waste and speeding up development. By integrating real-time data from IoT devices and sensors, DTs **optimize production processes**, enabling predictive maintenance and minimizing downtime. They also allow for **scenario simulation and prediction**, helping companies foresee issues and assess various solutions before making real-world changes. Additionally, DTs **promote sustainability** by reducing material and energy consumption through efficient virtual testing and optimization.

A company with a robust digital-twin platform, by contrast, can conduct comprehensive full-product simulations in a virtual environment before any proposed design is signed off on by the customer. Since complex machines typically use a combination of existing and newly engineered elements, companies can keep a library of digital-twin models of key components, combining them with the models of new parts to create the full digital twin. That twin can be used to demonstrate the proposed solution to the customer and verify that the new design meets their needs. And the digital-twin models of the new components can then be added to the library, making them available for future projects with similar requirements. [2] *Data Analytics Processes within DTs (SRC 🔗)*

So, DTs offer furniture manufacturers a powerful tool to enhance design precision, streamline production, engage customers, and promote environmental responsibility. Embracing this technology positions companies to thrive in an increasingly competitive and eco-conscious market.

Nevertheless, building a digital-twin platform is not as easy as it could be. That means a successful digital-twin program is a change management effort, requiring senior management commitment and support, and a strong program management team to track milestones,

[3]

Connecting Digital Twins = Seamless Digital Thread
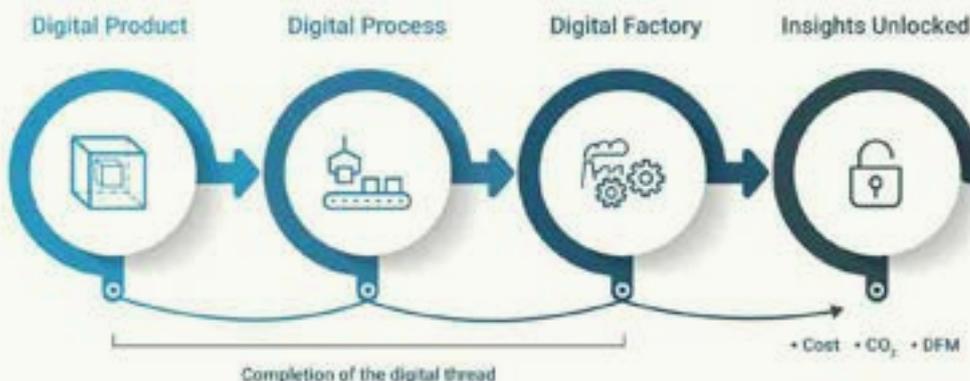
Digital Product · Digital Process · Digital Factory · Insights Unlocked

Completion of the digital thread

· Cost · CO₂ · DFM

develop new processes, and support their adoption by the organization.

[3] *Digital Roadmap of Manufacturers & Factories (SRC 🔗)*

To overcome these potential roadblocks, companies can adopt a phased approach to digital-twin adoption. The first three phases address the technological challenges of platform selection, architecture design, and integration: **Competitive Intelligence and Scoping**, where the organization assesses available solutions and estimates their potential value; **Architecture Design & Software Stack Definition**, which involves selecting the necessary software components and defining the system architecture; and **Software Development**, where the organization develops the processes and capabilities required to build, integrate, and launch its digital-twin platform. Subsequent phases focus on the organizational transformation required to support new processes and working practices.

Application

DTs in the furniture sector can be applied in different ways, depending on the specific needs of manufacturers, designers, and even end-users. They have the capabilities of **revolutionizing the furniture industry** by making manufacturing smarter, enhancing customer experiences, optimizing product design, and promoting sustainability. The following are some key applications that could be applied, all of them categorized by their purpose:

Smart Manufacturing & Process Optimization Application

DTs can simulate and optimize furniture production processes to reduce waste, improve efficiency, and predict potential failures in machinery. Bearing this in mind, a furniture factory could integrate a DT of its production line to analyse real-time performance and detect bottlenecks in different processes such as, cutting, assembly, or painting (among others). For that purpose, it is essential the usage of IoT sensors to monitor raw material usage and machine performance, preventing breakdowns before they happen. Along with this, the implementation of AI-driven simulations helps in waste reduction by suggesting more efficient cutting patterns for wooden panels. This application could lead to a 15-30% reduction in material waste and 10-20% improvement in production speed through real-time data analysis and predictive maintenance.

[4] *Smart Manufacturing & Process Optimization Application*

Virtual Prototyping & Customization Application

DTs allow furniture designers and customers to create virtual prototypes, test different configurations, and personalize furniture before physical production. Bearing this in mind, a company specializing in office furniture could create a DT of customizable desks and chairs letting its customers to adjust dimensions, materials, and colours in a virtual environment. The DT simulates then ergonomics based on user data, ensuring the furniture adapts to the end-user's needs before production and VR/AR module allow real-time visualization of how the customized furniture will look in an office or home setting. This application could lead to a shorter product development cycle by reducing physical prototyping and a higher customer satisfaction with personalized designs and ergonomic validation.

[5] Virtual Prototyping & Customization Application

[4]
[5]

Predictive Maintenance Application

DTs can monitor the performance of smart or industrial machinery in real time and predict maintenance needs. For example, a company manufacturing smart workstations may integrate sensors into their production cells to track usage patterns, structural integrity, and engine vibrations. The DT analyses this data to detect signs of wear and tear, enabling it to forecast when specific components require maintenance or replacement. This proactive approach helps facility managers address issues before failures occur, reducing unexpected downtime and lowering maintenance costs.

6 *Key Concept of Maintenance through Sensors (SRC ⬭)*

Sustainable Material Tracking & Circular Economy

DTs help track materials throughout the entire furniture lifecycle, supporting sustainable manufacturing and circular economy initiatives. As an example of this, could be a sustainable furniture brand creates DTs of all its products, tracking the origin of wood, fabrics, and metal components. Together with this, and leaning on IoT technology integration, users would be allowed to check how recyclable each component is and when the furniture reaches the end of its lifecycle, the digital twin suggests reusing or recycling specific parts, preventing waste. This application could lead to the support of eco-friendly design & sustainability goals and to enable furniture-as-a-service models, where customers can upgrade parts instead of replacing entire products.

7 *Digital Product Passport Concept (SRC ⬭)*

Implementation Aspects

■ **Implementation difficulty: Medium**

The adoption of DTs in sustainable manufacturing offers significant benefits but also presents challenges. Key obstacles include integrating production and sustainability metrics into a unified model, which can enable data-driven decisions balancing efficiency and environmental responsibility. Additionally, scalability and workforce readiness are critical, requiring skilled employees and cost-effective training, which DTs can facilitate through virtual simulations. Manufacturers also face the complexity of connecting every process and machine, alongside concerns about data accuracy, security, and privacy.

To overcome these hurdles, a gradual approach starting with process simulation and scaling over time can reduce risk. Furthermore, fostering a culture of innovation and upskilling employees are essential for successful implementation. Data integration and interoperability across diverse systems and legacy equipment remain a significant challenge for full-scale DT deployment.

■ **Economic viability: High**

Implementing digital twin (DT) technology requires a significant initial investment in sensors, IoT devices, software, infrastructure, and skilled personnel, which can be a barrier to entry. However, despite high upfront capital costs (CAPEX), the long-term benefits, including operational cost savings, improved efficiency, and revenue growth, often result in a strong return on investment (ROI). Focusing on areas like asset optimization,

6

Figure 1: Evolution of maintenance

1 — Visual inspection to detect issues / Reactive maintenance management / Allow assets to run to failure

2 — Preventative maintenance during pre scheduled time intervals / Reactive for unplanned breakdown

3 — Sensors to monitor issues in real time and send alerts / Conditional monitoring capabilities

4 — Cloud / Data warehouse to consolidate data from sensors, PLCs, ERP / Predictive algorithms for better accuracy and automated workflow

Lagging practices

Leading practices

predictive maintenance, and operational efficiency is key to maximizing the value of digital twin technology.

The adoption of digital twin technology in manufacturing remains limited to **large enterprises** with sufficient financial and technical resources. The complexity and scale of implementation make it challenging for small and medium-sized enterprises (SMEs) to deploy DTs effectively. While the simulation capabilities and production management improvements offered by DTs are significant, the current market landscape shows that their widespread use is still concentrated in industry leaders.

Human factors

Adopting digital twin technology often requires organizational changes and a cultural transformation. Resistance to change, digital illiteracy, or low awareness of the benefits may impede successful adoption. To ensure continuity, employees must upskill and bridge the digital divide without disrupting operations.

As such, DTs should be understood not as worker replacements, but as enablers of more intelligent and value-added tasks. New career paths are emerging at the intersection of human-machine collaboration—such as Digital Twin Operators, Process Intelligence Analysts, and XR Simulation Designers. Workers transition from traditional operators to co-creators in hybrid environments, responsible for supervising automation, making data-driven decisions, and fine- tuning processes.

In conclusion, the factory of the future does not aim to replace humans —but to enhance their capabilities. As machines handle routine tasks, human workers gain a central role in guiding, adapting, and improving intelligent systems. The challenge lies in equipping people with the right skills, mindset, and support systems to thrive in this augmented work reality.

Environmental factors

The implementation of DTs reduces the carbon footprint by optimizing energy consumption, minimizing waste, and improving efficiency in furniture manufacturing, as they can be mainly used to simulate manufacturing processes that lead to energy and resources saving, waste prevention, reduce physical testing, and optimize logistics routes, lowering CO_2 emissions and other environmental impacts. Together with this, DTs can be understood as an enabler for predictive maintenance, extending equipment lifespan and reducing unnecessary interventions. All these applications of DTs, could contribute to decrease significantly the environmental impact, guarantying that the manufacturer processes are aligned to environmental specifications and regulations.

Additionally, when implementing a DT in manufacturing, several environmental factors must be considered. These include energy consumption from data processing and hardware, the energy and water consumption of data centres and infrastructure, and resource usage (use of scarce materials), especially concerning material efficiency and e-waste. Additionally, manufacturers should focus on optimizing supply chain sustainability, managing data storage efficiently, and ensuring that the DT contributes to waste reduction and energy optimization in production. Compliance with environmental regulations, life cycle assessments, and the application of ecodesign criteria are also key considerations to minimize the environmental impact of the DT.

Another aspect is the connectivity through Internet of Things (IoT) devices, cloud computing, and real-time data analytics. The manufacture and maintenance of sensor networks used to gather telemetry data—such as accelerometers, thermal sensors, and RFID tags—incur material and energy environmental impacts. These devices often use rare earth elements, lithium batteries, and specialized semiconductors, whose extraction and processing contribute significantly to GHG emissions, **energy usage**, water pollution, and toxic waste **and in general, being difficult to recycle at their end-of-life.**

Alignment with certifications and regulations

Implementing a DT in a factory involves compliance with several regulations and standards related to data security (ISO/IEC 27001, IIC Security Framework), privacy (GDPR), cybersecurity (NIST), interoperability (IEC 62264 / ISA-95), environmental impact (Paris Agreement & Net Zero Goals, ISO 14001) and industry-specific requirements (CCPA, AI Act, ISO 50001). These rules and standards are crucial for ensuring data privacy, cybersecurity, energy efficiency, and sustainable manufacturing practices.

BRAND/DESIGNER
- Origin of raw materials
- Recycled vs virgin
- Resource consumption

MANUFACTURER
- Water usage
- Emissions
- Waste
- Water and ground contamination

RAW MATERIAL PRODUCER
- Deforestation
- Emissions
- Water and ground contamination

DISTRIBUTOR
- Transport emissions
- Packaging
- (Eco-) labels
- Waste generation

COLLECTOR/RECYCLER/ REFURBISHER/ REMANUFACTURER
- Disassembly instructions
- Recycling instructions
- Repair history

(RE-) USER/REPAIRER
- Product impact
- User manual
- Repair instructions
- Disposal instructions

RAW MATERIALS · DESIGN · MANUFACTURE · DISTRIBUTE · USE/REPAIR · COLLECT · RECYCLE

Digital Product Passport

Source: ebcsblog/Pathways-Products and Materials-Resources-The-EU-Digital-Product-Passport

Smartize Product Development Processes with the adoption of Digital Twin Technologies

Solutions

Digital Twin for Manufacturing
TWINZO
Slovakia ⌐⊃

Twinzo is a mobile-first, real-time 3D digital twin platform designed to provide comprehensive visibility into manufacturing and logistics operations. It enables users to create live digital replicas of facilities—such as factories, warehouses, or entire cities—that integrate IoT sensor data, RTLS (Real-Time Location Systems), and operational metrics into an interactive 3D environment accessible via smartphones, tablets, or desktops.

Digital Twin for Manufacturing
Siemens
Germany ⌐⊃

Siemens Xcelerator is a comprehensive digital business platform that helps companies streamline product design, manufacturing, and operations through a powerful combination of software, hardware, and services. For the furniture industry, it enables the creation of detailed digital twins for products and production lines, supports custom and modular designs, and offers tools for factory simulation, IoT integration, and low-code app development. With solutions like Teamcenter for PLM, Tecnomatix for process optimization, and Mindsphere for smart factory insights, it empowers furniture manufacturers to improve efficiency, reduce waste, and accelerate innovation from concept to customer.

Digital Twin for Manufacturing
Microsoft
United States ⌐⊃

Azure Digital Twins is a platform from Microsoft that enables the creation of comprehensive digital models of real-world environments, such as buildings, factories, or entire supply chains. It uses an open modeling language (DTDL) to define entities, relationships, and behaviors, making it ideal for simulating complex systems in real time. In the context of industries like furniture manufacturing or retail, it can model everything from factory workflows to store layouts, track assets with IoT data, and power smart analytics for optimization and sustainability. Integrated deeply with the Azure ecosystem, it supports scalable, secure, and intelligent digital twin solutions.

Digital Twin for Manufacturing
Bentley's Systems
United States ⌐⊃

Bentley's iTwin Platform is primarily known for infrastructure and engineering, but it also offers powerful tools for modeling and simulating industrial and manufacturing environments. It enables the creation of rich, real-time digital twins that integrate design data (from BIM/CAD), sensor feeds, and operational systems into a single, connected view. For manufacturing, this means you can visualize factory layouts, monitor equipment performance, simulate processes, and optimize operations across the asset lifecycle. With strong support for reality modeling and integration with IoT platforms, Bentley's digital twins help improve asset reliability, workflow efficiency, and data-driven decision-making in complex manufacturing facilities.

Digital Twin for Manufacturing
PTC INC
United States ⌐⊃

ThingWorx, developed by PTC, is a robust industrial IoT and digital twin platform designed to connect, analyze, and optimize physical assets and operations. It enables manufacturers to create real-time digital representations of products, machines, or entire production lines, combining data from sensors, systems (like ERP/PLM), and user inputs. ThingWorx excels in supporting predictive maintenance, remote monitoring, and performance optimization, especially in manufacturing environments. It also integrates with Vuforia for augmented reality, allowing users to interact with digital twins in immersive ways—ideal for training, troubleshooting, or custom product visualization. Its flexibility and low-code tools make it a strong fit for companies looking to accelerate digital transformation across engineering and operations.

B SOLID Digital replica simulation software for CNC
BIESSE
Italy ⌐⊃

B-SOLID gives users a view into their CNC machine by creating a digital twin, allowing them to design a machining programme for any specific project, running a realistic 3D simulation of that task, verifying machining speed, tool selection, and estimating the job completion time. Performing a collision check in the virtual environment allows to highlight any contact between machine parts, avoiding clashes between the machine head and worktable.

Digital Twin software for CNC machines
SIEMENS
Germany ⊖

Siemens NX, combined with Sinumerik One, enables the development of a true digital twin of the CNC system, accurately simulating machine tool behavior. This advanced technology has been adopted by CMS (part of the SCM Group) in its hybrid CMS Kreator platform. By leveraging the digital twin, CMS can validate toolpaths, prevent collisions, and optimize manufacturing processes before physical execution. The system also incorporates MindSphere and Edge Computing for real-time monitoring and predictive maintenance. This approach is particularly valuable for manufacturers of woodworking machines, helping to reduce commissioning times and enhance overall operational efficiency.

Sustainable furniture design through Digital Twins
AMUEBLA
Spain ⊖

In the AMUEBLA project, developed with SANCAL and AIDIMME, digital twins are used to validate regulations and sustainable designs before physical manufacturing. This case is a strong example of how digital twin technology supports compliance and sustainability goals in the furniture industry.

Circularise
Circularise
The Netherlands ⊖

Blockchain-based platform to trace material origin, lifecycle and recyclability for circular manufacturing.

Dassault Systèmes DELMIA
Dassault Systèmes
France ⊖

Enables advanced manufacturing simulation and optimization, helping furniture producers streamline production, manage resources and reduce downtime.

SAP Predictive Asset Insights
SAP
Germany

Predicts maintenance needs of smart furniture using IoT and machine learning analytics.

Autodesk Configurator 360
Autodesk
United States ⊖

Web-based 3D configurator platform for creating customizable furniture models integrating parametric CAD design.

Topsolid Wood
TopSolid
France ⊖

TopSolid'Wood is an integrated CAD/CAM software tailored for the wood industry, enabling end-to-end project management from design to production. It offers unlimited 3D modeling, customizable machining functions, and seamless integration with CAM and cutting optimisers, boosting productivity for woodworking professionals and manufacturers.

Smartize Product Development Processes with the adoption of Digital Twin Technologies

Twinzo
Slovakia

Digital Twin for Warehouse Management: Logistic operators navigate around the facility, searching for materials to deliver or empty packaging to remove from the line, often doing so randomly or following predefined cycles. This practice frequently leads to idle periods in production throughout the day due to material shortages, resulting in cumulative downtime. Additionally, there is a prevalent issue of uneven driver utilization, with some operators overloaded while others engage in non-productive activities such as browsing social media.

Siemens
Germany

Transforming the industry for tomorrow: DMG MORI, a leading global manufacturer of machine tools, offers the first end-to-end Digital Twin of a machine tool on the Siemens Xcelerator Marketplace. Developed in close cooperation with Siemens, this pioneering innovation represents a true milestone for the industry – a solution that can be scaled to meet individual customer needs.

Visual Components
Finland

Digital Twin for Bathroom cabinet production: Today's customers demand personalized products while also expecting low prices, which creates a challenge for manufacturers. This apparent contradiction arises because product variety increases production complexity. However, mass customization offers a solution, as seen in industries like automotive and bathroom furniture. Companies like MBFZ toolcraft GmbH specialize in advanced technologies, such as individual turnkey robot solutions, helping manufacturers adapt to this trend. MBFZ, founded in 1989, has become a leader in this field, offering innovative solutions for industries like aerospace, medical technology, and automotive, allowing businesses to efficiently manage customization at scale.

Siemens
Germany

Girsberger simulates and optimizes wood cutting operations offline using a digital twin: Describes how Girsberger has optimized their manufacturing processes by the adoption of digital twin technologies as they can test and optimize the wood cutting operations offline using the machine's digital twin, saving time and unsuccessful attempts and avoiding collisions.

Dassault Systemes
France

Virtual Testing Using PowerFLOW: Virtual Testing Using PowerFLOW: The kitchen has become a central hub for families and for entertaining in modern homes. Kitchen designs and functionality are evolving to accommodate more activities, reflecting a shift from practical to versatile living space. Researchers at the Silestone Institute published a Global Kitchen Study, which found that kitchens today transcend traditional roles by functioning as vibrant centers for various activities, including socializing, working, and dining. Open layouts with comfortable seating and innovative design elements can transform kitchens into inviting social spaces where people enjoy gathering while providing the practical comfort to create delicious snacks and meals.

Digitiza Designs
United States

Transforming Interior Design with 3D Scanning Technology: Exact measurements are essential, and unlike most online retail, furniture often needs to be judged in-person for texture, comfort, and style. Rooms To Go aimed to overcome these challenges by creating digital furniture models so realistic they can be used by interior decorators to virtually weigh up decor, achieve the perfect look and feel, and realize their creative visions.

Beamo
Republic of Korea

Hospitality Industry Digital Twin Application Case: Beamo's digital twin platform utilizes 360-degree cameras and smartphones to create virtual replicas, finding applications beyond traditional industries. A hotel facility successfully implemented the technology for marketing and representation. Achieving cost savings, reduced data expenses, and improved workflow and documentation. The versatile applications of digital twin technology continue to evolve, showcasing its positive impact across different sectors.

Denodo Technologyes
United States

A Real Time and Data Virtualization Case Study: Describes how CITY Furniture took the success of a real-time data system for sales and extended it across multiple departments. The journey begins with a software engineer and an IBM mainframe and ends with a data democratization initiative. There are many interesting stops along the way–a streaming layer, an IBM cloud data warehouse, a miscellany of data stores, a data fabric, and data virtualization.

Cetem
Spain

A digital twin for furniture will allow prototype testing to be brought forward for compliance with industry and legal regulations: AMUEBLA has applied for an innovative project together with AIDIMME, CETEM, ARVET, and the company SANCAL, which aims to improve the design of the prototype by means of digital twin simulations for legal and industrial compliance before its manufacture, also reducing costs due to non-compliance with the standard.

-
China

A digital twin workshop model was applied to the packaging process in panel furniture manufacturing to improve integration with information systems. Implemented in Company W, it identified inefficiencies, proposed optimizations, and, through simulation and real testing, increased packaging line efficiency by 20% while reducing labor by 5–6 workers. The model supports intelligent manufacturing and system upgrades.

Hamon
France

Modernisation of obsolescent machinery: In the retrofit project of a machine used to cut wooden planks to uniform dimensions and quality, a digital twin has been implemented (by the Actemium system integrator, basing on Rockwell Automation's Emulate 3D Dynamic Digital Twin software), to develop and test the new automation programs offline, optimise the program code and to anticipate potential problems before real-machine tests. A significant reduction of the downtime has been achieved

Simplan
Germany

Digital Twin simulation to analyze the production processes: Siemens software Plant Simulation is used by Nolte-Möbel, a German furniture manufacturer, to optimize its complex pre-production workflows. The software creates a digital twin of the production environment, integrating real data from Excel for precise modeling. Nolte uses it to simulate planning scenarios and process variations without disrupting ongoing operations. The tool provides full visibility into material flow and resource utilization.

FlexSim Software Products, Inc
United States

FlexSim customized furniture process twin modelling: Simulation-based study of mass customized furniture production using FlexSim 3D software on a Polish company. It analyses how increasing production volumes affect machine workload and system efficiency. Recommendations include adding equipment and optimizing material flow to enable scalable, efficient production, supporting growth up to ten times current capacity.

Girsberger Holding AG
Switzerland

Optimizing furniture production with a Digital Twin: Girsberger, a furniture company, optimizes wood cutting using a digital twin to prevent collisions and enhance production efficiency. This practical implementation helps illustrate the capabilities of ThingWorx in a tangible and relatable way.

Increasing the Safety and Productivity of Manufacturing Processes while minimize their Environmental Impact, by the adoption of simulation techniques within Digital Twins
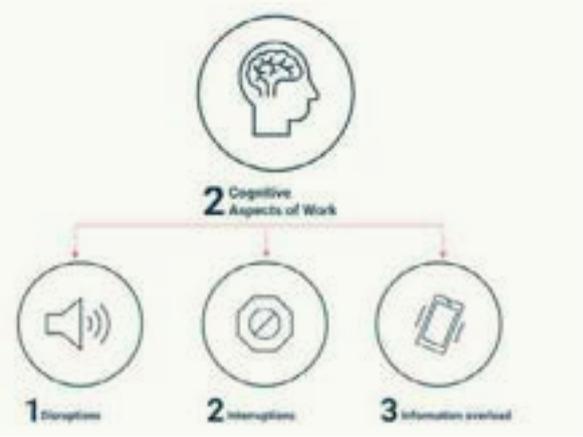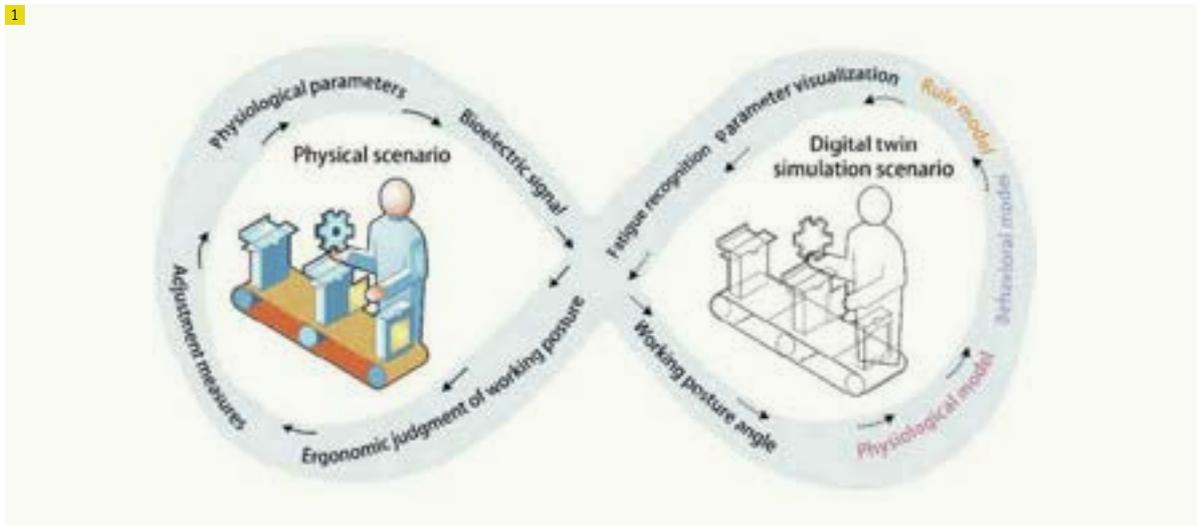
Implementation difficulty: **Medium**
Economic viability: **High**

Increasing the Safety and Productivity of Manufacturing Processes while minimize their Environmental Impact, by the adoption of simulation techniques within Digital Twins

Description

Digital twins (DTs) are becoming essential in driving sustainability in the evolving manufacturing sector. Their predictive capabilities help reduce downtime, extend equipment lifespan, and minimize waste through proactive maintenance and risk mitigation. By integrating real-time data from sensors and machines, DTs create accurate virtual replicas of physical systems, allowing manufacturers to simulate scenarios, optimize processes, and identify issues without interrupting production. As such, the continuous comparison between real-time data and data obtained from the simulation can be used by the software to improve the DT's understanding of the real-world issue, hence resulting in **more accurate simulations**, leading this way to contribute enormously to the sustainability of the manufacturing processes.

Additionally, in the era of Industry 5.0, the human-centric approach in manufacturing is crucial. Considering the aging workforce and the increasing number of women entering traditionally male-dominated jobs, it is crucial to incorporate this diversity into the ergonomic design of systems and environments, while also tailoring workplaces to suit all individuals.

Bearing this in mind, the use of DTs together with **ergonomic simulation** has contributed recently for increasing both safety and productivity in the workplace.

[1] *Digital Twin approach for Human Ergonomics Simulation (SRC ⇄)*

The field of ergonomics has evolved in the last few decades to include both simulations in 3D environments and Artificial Intelligence techniques to estimate work related musculoskeletal disorders (MSDs). With advancements in simulation speed and intuitive interfaces, the time required to develop ergonomic simulations has dropped dramatically and made them more practical. Traditional ergonomic analysis involved the use of MTM tables and generic rules-of-thumb to incorporate safety factors and heuristics to ensure job safety. This approach often made it difficult to assess unique tasks or forced engineers to error on the side of expensive solutions to ensure safety. To reduce this gap, DT approach to design and process management has put better tools at the engineer's fingertips faster than ever as DT allows to assess ergonomics from a physical and cognitive perspective.

Physical Ergonomic Simulation consists of assessing the physical ergonomic environment entails looking at operator reach, assessing the stresses and strains on the body, measuring kilocalories expended to determine fatigue, and analysing postures and movements using observational-based tools like RULA (Rapid Upper Limb Assessment) REBA (Rapid Entire Body Assessment), OWAS (Ovako Working Posture Analysing System) and OCRA (Occupational Repetitive Actions Index). When assessing reach, simulations make it easy to change the anthropometry of the manikin in the simulation to make sure that the smallest female or largest male can both accomplish a task easily. Based on a specific chosen standard or weight, the simulation can be configured to assess a body position during a task. Simulations can also be used to assess accessibility for specific task by determining cycle time and checking that the worker's posture remains in an acceptable state during the entirety of the task.

[2] *Physical Ergonomics in Manufacturing Processes (SRC ⇄)*

Movements and postures of the manikins are often driven by the data obtained by leveraging optical devices or inertial sensors mounted on the tracked person's body in real scenarios. Although robust, these systems are costly, have setup limitations and are challenging to us in real working environments to made reliable and realistic simulations. Machine learning, and in particular Deep Learning techniques allow the human body joints to be recognized by videos captured from RGB cameras and directly assess ergonomic indexes or support simulations.

Cognitive Ergonomic Simulation analyses the mental side of a task. Often this refers to the visual cues provided to a worker to help them do their tasks and minimize the mental stress related to their job. The field of cognitive ergonomics is embracing the concept of a DT to allow workers to experience a work environment before it is built as it is somehow demonstrated that with poor cognitive ergonomics comes cognitive strain: disruptions (e.g. speech, noise, and moving elements around, etc.); interruptions (e.g. co-workers asking for help, interaction technologies and notifications, missing information, or decision that blocks the continuity of work, etc.); information overload (e.g. multitasking, monitoring and observing several things in parallel, changing between tasks while working, etc.).

[3] Cognitive Strain Sources in Manufacturing Processes (SRC ⇄)

Increasing the Safety and Productivity of Manufacturing Processes while minimize their Environmental Impact, by the adoption of simulation techniques within Digital Twins

Application

It is widely known that DTs play a key role in reducing the environmental impact of manufacturing by enhancing sustainability across processes. They enable resource optimization by analyzing material use, waste, and energy data to identify inefficiencies. Through virtual simulations, DTs help lower energy consumption while maintaining output quality. For example, Digital Twins allow the creation of realistic virtual prototypes that replicate products or processes, reducing the need for costly, time-consuming physical prototypes. This lets defects be identified and corrected during the design phase, lowering material, labor, and time costs, as well as energy use. Modifications can be tested quickly, accelerating development and time-to-market while improving final product quality.

They also support waste reduction by enabling predictive maintenance and extending equipment lifespan. Additionally, DTs facilitate circular production models like recycling and remanufacturing by optimizing material flows and resource recovery. Bearing this in mind, DTs could also be used to simulate how workers behave to improve safety, speed, and efficiency in manufacturing. The answer is yes, but challenges arise in replicating human movements and ergonomics.

One significant challenge lies in achieving accurate representations of human movements, considering sensor accuracy and biomechanical modelling limitations. Data latency and synchronization issues also hinder real-time responsiveness, creating discrepancies between simulated and actual movements. Integrating diverse data sources and technologies adds complexity due to compatibility issues and interoperability constraints. Privacy and ethical concerns about collecting and processing human movement data further highlight the need for safeguards that protect individual rights.

[4] *Digital Twins for Ergonomics Assessment in Manufacturing Processes*

Simulating human-robot interaction requires advanced modelling and control algorithms to achieve seamless collaboration. Scalability issues, lack of standardisation, and the absence of best practices further impede adoption, underscoring the need for industry-wide guidelines. Addressing these challenges through advanced modelling techniques, machine learning, deep learning, enhanced data integration, and ethical frameworks is essential to unlock DTs' full potential in human simulation.

Additionally, DTs could be used to visualize the entire workforce under different scenarios, showing how employees would perform best under specific conditions and enabling precise resource planning. Virtual representation of each employee allows predictive oversight, ensuring problems are anticipated and solved proactively.

[5] *Digital Twins for Staff Controlling and Planning*

DTs offer transformative potential for workforce management by allowing organizations to simulate and optimize employee-related decisions before implementation. They enhance forecasting with accurate, data-driven staffing predictions, reduce risks in organizational change, and support strategic planning. By mapping skills and performance in real time, companies can allocate resources more effectively, create personalized career paths, optimize scheduling, and adapt quickly to changing demands.

Overall, DTs boost efficiency, ensure better role alignment, and support continuous workforce development and agility. Put simply, DTs help organizations prepare for unexpected events like workforce demand shifts, turnover, or new projects. They can be seen as tools for anticipating long-term developments, identifying risks and opportunities. Unlike fixed models, DTs use real-time information to represent the workforce dynamically, simulating team reactions to scenarios such as workload changes or revised schedules.

Implementation Aspects

Implementation difficulty: Medium

Implementing manufacturing process simulation, especially for ergonomics, presents challenges such as integrating real-time data, the need for technical expertise, and resistance from staff. Human-related barriers include scepticism toward digital tools, lack of ergonomics awareness, and fears of surveillance or job evaluation. Additionally, managers may prioritize productivity over ergonomics. Overcoming these challenges requires clear communication, inclusive planning, training, and demonstrating the value of ergonomics for both safety and efficiency. A careful, gradual implementation with the right software and resources can support successful adoption.

Economic viability: High

Economic barriers can significantly impact the adoption of ergonomic simulation technologies, especially for small and mid-sized manufacturers due to high upfront costs for software, hardware, training, and consultancy. These companies often prioritize short-term productivity over long-term ergonomic benefits, which may be harder to quantify financially. However, with strategic planning, clear communication of long-term gains, and gradual

implementation, simulation can ultimately lead to safer, more efficient, and cost-effective operations.

The full deployment of a digital twin for complete process control remains a significant challenge. It requires extensive **parameterization, system integration, and continuous data alignment**, which can demand substantial time, expertise, and financial investment. Therefore, companies must **prioritize deployment areas** based on impact potential, starting with high-consumption or high-risk processes.

■ Human factors

A key human factor in ergonomics simulation is user acceptance and engagement. Workers and managers may resist digital tools if these are perceived as intrusive, controlling, or designed mainly for performance evaluation rather than supportive aids. This scepticism intensifies when technologies such as motion capture or VR are introduced without clear explanation of their purpose and benefits. Successful implementation requires not only a baseline understanding of the tools and ergonomic principles but also well-structured training and onboarding programmes. Digital literacy varies widely across roles—operators, engineers, and supervisors may have different familiarity with advanced platforms—creating uneven adoption if not addressed.

Another pitfall occurs when simulations are developed solely by technical teams, without input from those performing the tasks. This top-down approach often produces models that miss the subtleties of workflows or shop-floor challenges. Establishing participatory processes where workers contribute to design, testing, and validation ensures accuracy, strengthens ownership, and improves acceptance. Clear communication about objectives, benefits, and limitations also fosters trust and collaboration.

Finally, ethical concerns must be managed. Employees may fear surveillance, misuse of personal data, or loss of autonomy when their movements are recorded and analysed. Misinterpretation of data can undermine trust. Organisations must therefore establish transparent policies governing data usage, obtain informed consent, and guarantee secure handling practices. Addressing privacy issues proactively and promoting transparency builds a trust-based environment where technology is viewed as a collaborative tool designed to support, rather than threaten, workers.

■ Environmental factors

Environmental factors also influence the accuracy and usefulness of ergonomics simulations. A facility's layout must be realistically modelled to ensure effective assessments. Conditions such as lighting, temperature, humidity, and noise can significantly affect worker comfort and performance. Poor environments may increase stress, reduce concentration, and heighten ergonomic risks. Including these variables in DT simulations provides a more holistic understanding of workplace conditions.

Sustainability is another essential consideration. DTs themselves consume resources: data processing, hardware, and supporting infrastructures like data centres require significant energy and water, while using scarce materials that contribute to e-waste. Managing data storage efficiently and applying ecodesign principles helps reduce environmental impact. Life cycle assessments and compliance with regulations such as ISO 14001 are critical to minimising DTs' footprint.

Connectivity adds further challenges. DTs rely on IoT devices, cloud computing, and real-time analytics. Manufacturing and maintaining sensor networks—accelerometers, thermal sensors, RFID tags—entails material and energy costs. These devices often use rare earth elements, lithium batteries, and semiconductors, whose extraction and processing generate greenhouse gas emissions, water pollution, toxic waste, and recycling difficulties.

■ Alignment with certifications and regulations

Implementing a Digital Twin (DT) in manufacturing requires compliance with key standards, including ISO/IEC 27001:2022 for data security, GDPR (2016) for privacy, NIST (2018) for cybersecurity, ISO 14001:2015 for environmental impact, ISO 50001:2018 for energy management, and ISO 45001:2018 for workplace safety. Ergonomics and interoperability are addressed by ISO 9241 (2019), EN 1335:2020, and IEC 62264 (2013), ensuring sustainable, secure, and efficient operations.

Increasing the Safety and Productivity of Manufacturing Processes while minimize their Environmental Impact, by the adoption of simulation techniques within Digital Twins

Solutions

Human-focused Manufacturing
Siemens
Germany ⊂⊃

Tecnomatix is a comprehensive digital manufacturing software suite developed by Siemens Digital Industries Software. It enables manufacturers to digitally plan, simulate, and optimize production processes, facilitating the transformation of innovative ideas into tangible products. By integrating real-time data from various manufacturing disciplines, it helps synchronize product engineering, manufacturing engineering, production execution, and service engineering, thereby maximizing manufacturing efficiency.

Digital Human Modelling in Virtual Ergonomics
Dassault Systemes
France ⊂⊃

DELMIA helps manufacturing engineers design safe and efficient workplaces virtually to avoid costly mistakes in the physical world. Our Virtual Ergonomics software enables designers and engineers to overcome posturing problems by simulating human interaction and ergonomic behaviour between a product and a system from the earliest stages of the design process. Product designers and manufacturing engineers can resolve ergonomic problems virtually as early as possible to increase employees' well-being, decrease the costs of work-related injuries and increase productivity in the real world. Moreover, they can make quick and efficient decisions to reach their design goals by providing relevant guidance to product and workplace designers, even those with a low ergonomic background.

Occupational risk prevention software powered by AI
Siali Technologies
Spain ⊂⊃

Safe is the platform that automates your company's EHS by anticipating any accident to improve the safety of your employees. It is an active tool in risk prevention. It detects and alerts in real time about all potential hazardous situations, such as lack of PPE, obstructed pathways, vehicle speed. to take action before it becomes serious.

Ergonomic Digital Twin
Moovency
France ⊂⊃

KIMEA is an innovative ergonomic digital twin solution designed to assess and prevent musculoskeletal disorders (MSDs) in workplace environments. By utilizing depth-sensing cameras, such as Microsoft Kinect, KIMEA captures 3D skeletal data of workers performing tasks. This data is then processed through advanced algorithms to correct for potential occlusions and inaccuracies, ensuring precise analysis even in complex industrial settings. The system creates a real-time digital twin of the operator, automatically converting gestures and postures into ergonomic indicators. This allows for dynamic analysis of MSD risks, enabling organizations to prioritize interventions effectively and implement targeted prevention strategies

Intelligent Safety Analytics
Soter
United States ⊂⊃

SoterAI, the AI-first platform giving EHS leaders unprecedented risk visibility and predictive power. The platform securely analyses complex, multi-source enterprise safety data to identify emerging risks and predict potential incidents before they happen. It delivers the actionable insights you need to proactively mitigate risk, assure compliance across all sites, and optimize your overall EHS strategy for measurable business results.

Cognitive Digital Solutions for Industry Leaders
Cognitwins
United States ⊂⊃

CogniTwins, helps to harness the power of Cognitive Digital Twins, Threads, and Swarms to successfully transform current business and create new future-proof lines of smart Products, Solutions, and Services.

DT for the analysis of the industrial assets' lifecycle
Hexagon
Sweden ⊂⊃

HxGN SDx2 is a cloud-native platform developed by Hexagon for managing the entire lifecycle of industrial assets. It integrates real-time 2D/3D visualizations, engineering and operational data, enabling predictive maintenance, improved safety, and data-driven decisions. Built on Microsoft Azure, it supports digital twin environments for industrial efficiency and sustainability.

HEGO
Emoj
Italy ⌐

The Body Tracker by Emoj, called HEGO, is an AI-powered, non-invasive system designed for real-time monitoring of workers' posture and movements. It assesses ergonomic risks by analyzing various body positions and angles, such as head and torso flexion, arm movements, and joint angles. The system calculates international ergonomic indices like REBA, RULA, and OCRA, providing a detailed risk assessment for musculoskeletal disorders (MSDs). Data is accessible through a dashboard for both companies and ergonomists, enabling proactive interventions and personalized workplace adjustments. Fully compliant with GDPR, Body Tracker enhances workplace safety and ergonomics without the need for intrusive equipment

Sustainable Manufacturing
Institute of Industrial Technologies and Automation (ITIA) – National Research Council (CNR)
Italy ⌐

The "Sustainable Manufacturing" project, led by ITIA-CNR and involving major partners like Politecnico di Milano and Università Politecnica delle Marche, aims to develop enabling technologies and methodologies for sustainable product and factory design across the full product lifecycle. It promotes eco-design, efficient resource use, and people-centered production. Applications span polymer formulation, eco-factories, and de-manufacturing. Key innovations include energy-efficient systems, sensor-equipped workwear, intuitive multimodal interfaces, and augmented reality for factory monitoring. The project also develops new business models for circular manufacturing. Supported by a wide network of companies, it strengthens Italian leadership in high-performance, sustainable manufacturing systems. During the Project, particular attention was paid to test different ergonomic assessment tools integrated with DT of the involved factories, in order to identify potential applications to reduce MSDs, to improve the design of workbeches and in general industrial sustainability.

Health and safety training through Digital Twin
PREVU3D
Canada ⌐

Prevu3D is a digital twin software to visualize assets in 3D, enabling real-time monitoring of their operational state and historical data. The platform offers immersive navigation modes, from walk-through to top-down CAD views, enhancing visibility and alignment among teams. Its advanced 3D scanning and mesh processing support capacity planning and simulate layout changes without physical presence. Prevu3D also empowers organizations to enhance employee training through immersive 3D scenario testing, helping prioritize safety and minimize operational risks.

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Examples

Ford
United States

Ergonomics Meets Immersive Engineering: Assembly-line work is not easy. Producing a vehicle every 60 seconds requires a lot of stretching, reaching, lifting, pulling and pushing. By bringing motion tracking and simulation to a new peak in immersive engineering, Ford Motor Co. is making huge gains through ergonomic analyses in dramatically reducing assembly injuries. As an added benefit, quality has improved.

BMW Group
Austria

Reducing lifecycle energy consumption of car engines with Plant Simulation: Car makers typically manufacture most of the core parts and components of their engines in-house. Crankcase, crankshaft, cylinder head and connecting rods are lathed, milled, drilled, ground and honed on sophisticated production and transfer lines in plants such as BMW Motoren GmbH, the biggest engine plant within the BMW Group located in Steyr, Austria, about three hours' drive from the Munich, Germany headquarters.

Electrolux
United States

Worldwide 3D factory and material flow planning: With the good visualization possibilities of Tecnomatix, I can show the management an early stage of planning that makes the processes plausible. The 3D technology helps with the verification of assembly concepts as well as with the selection of suppliers for automation solutions and provides insights that I didn't have before.

KONE
Finland

Looking for a 3D simulation and layout planning tool: KONE decided it was time to look for a solution that could not only help them with planning and designing new production solutions, but also improve their communication with stakeholders during the planning and development process.

Volkswagen
Germany

"Virtual human" tool improves ergonomics: Ergonomics used to be a foreign-sounding word that meant little to companies, but nowadays, it could have a major impact on productivity levels. Imagine that the ergonomics of a workstation are ignored – the results could be disastrous. Consider this scenario: a particular bolt connection is hard to reach for a worker, and consequently it is difficult for the worker to tighten the bolt. The assembly line continues at a relentless speed, and the worker has a hard time keeping up, making his or her already uncomfortable position more painful in trying to continue working. The result of this could be that the entire production line screeches to a halt – an outcome no company can afford. In some situations, it might not even be possible to meet delivery times.

CETEM
Spain

Digital twin detects where to improve furniture safety and proposes redesigns for new prototypes: The Predictive Artificial Intelligence-based system for furniture testing will support the efficiency and productivity of the Spanish furniture sector and save costs, but will not replace traditional physical testing, which is necessary for national and international product certifications through accredited laboratories.

University of Campania Luigi Vanvitelli
Italy

Digital Twin for Monitoring Ergonomics during Manufacturing Production: Within the era of smart factories, concerning the ergonomics related to production processes, the Digital Twin (DT) is the key to set up novel models for monitoring the performance of manual work activities, which are able to provide results in near real time and to support the decision-making process for improving the working conditions. This paper aims to propose a methodological framework that, by implementing a human DT, and supports the monitoring and the decision making regarding the ergonomics performances of manual production lines. A case study, carried out in a laboratory, is presented for demonstrating the applicability and the effectiveness of the proposed framework. The results show how it is possible to identify the operational issues of a manual workstation and how it is possible to propose and test improving solutions

KITT4SME
Italy

Health, safety and ErGOnimics for the future human-centric factory: The Project, funded by KITT4SME's Type-A Open Call (n. 952119), involved the development of an AI-powered ergonomic assessment tool applied within Salvarani, a Reggio Emilia-based manufacturer of agricultural machinery. The AI system analyzed workers' movements and postures in real-time, automatically calculating ergonomic risk indices such as REBA and RULA. Results demonstrated that the AI-based assessment was not only comparable to traditional methods using virtual mannequins and expert observations, but in some cases even more accurate and consistent. The tool enables continuous, non-invasive monitoring, offering a scalable solution for improving workplace ergonomics across industrial settings.

Biesse Group and Università Politecnica delle Marche
Italy

The Intelligence 5.0 project, carried out by the Università Politecnica delle Marche and Biesse (a leading manufacturer of furniture processing machinery), tackled the growing need for predictive maintenance and diagnostics in the mechatronic sector, leveraging Industry 4.0 technologies. These services, though promising, have often been underused due to complexity, lack of expertise, and uncertain returns. The project developed a new generation of "self-aware" machines, integrating Digital Twin, AI, Knowledge Management, and Augmented Reality. These systems collect real-time data, process it through cognitive models, and suggest optimal maintenance and production strategies. A user-centric approach ensured alignment with real operational needs. The result: increased machine reliability, reduced downtime, and smarter decisions across design, operation, and logistics.

Biesse Group
Italy

Digital Twin for the Wood and Furniture sector: Biesse Group uses B_SOLID, a Digital Twin software that simulates CNC woodworking machines in 3D. It enables virtual testing of machining processes, preventing errors, optimizing tool paths, and improving production efficiency. This innovation enhances product quality, reduces waste, and supports predictive maintenance in the wood-furnishing industry.

TuMeke Ergonomics
United States

AI-powered platforms for risk assessment: TuMeke's AI-powered platform enables real-time monitoring of workplace posture and movements using computer vision, identifying ergonomic risks automatically. It centralizes data across multiple sites in a unified dashboard, eliminating inconsistencies and enabling standardized assessment. The system provides instant alerts on hazardous behaviours (like unsafe lifting or repetitive motions) empowering timely interventions. It accelerates risk assessments up to 20x compared to traditional methods and reduces injuries by as much as 68%, improving workplace safety.

BMW Group
Germany

Innovative 3D Human Simulation to plan and train for future production: BMW Group Plant Regensburg uses advanced "3D human simulation" technology integrated within the factory's Digital Twin to plan the production of the new NEUE KLASSE vehicle generation years in advance. This digital simulation faithfully reproduces not only the factory environment and assembly lines but also the movements and tasks of operators, enabling ergonomic analyses and workflow optimizations. Operators can also be trained early using VR goggles that immerse them in a realistic virtual environment, improving efficiency and safety before actual production begins. This project marks an important step towards BMW's intelligent, connected factory of the future, reducing planning time and costs while enhancing the quality of human work on the shop floor.

7

Implementation difficulty: **High**
Economic viability: **Medium**

Product traceability in the furniture sector through the Digital Product Passport (DPP)

Description

Product traceability refers to the ability to track the origin, history, and movement of a product and its components throughout the entire value chain. It is a key enabler of sustainable production, regulatory compliance, and consumer transparency. In this context, the Digital Product Passport (DPP) emerges as a central tool to structure and share product-related data across its lifecycle.

The DPP is a core element of the EU Eco-design for Sustainable Products Regulation (ESPR), aimed at enhancing transparency, circularity, and sustainability. Although the DPP is not a technology itself, its implementation relies on a set of digital tools that enable structured, secure, and real-time data sharing.

Central to the DPP are enabling technologies that allow each physical product to be uniquely identified and digitally connected to verified information. These include:

QR codes, barcodes, RFID or NFC tags, which act as data carriers embedded on the product to ensure secure access to its digital identity;

Cloud-based platforms, which securely manage and store structured lifecycle data;

Blockchain technologies, which can provide data integrity, transparency, and authentication;

Digital twin systems, which create a virtual representation of each product, providing information about what it is, who has control over it, where it is geographically located throughout the supply chain, and continuously updating with data on materials, processes and sustainability metrics.

These technologies enable the secure collection and controlled sharing of a wide range of information, such as raw material sourcing, manufacturing details, carbon footprint, recycled content, safety compliance, repair instructions, and end-of-life options.

1 *DPP – Information sharing*

Consumers, regulators, and supply chain actors can access selected data instantly by scanning a code or interacting with a digital interface.

2 *DPP - QR code technology*

The ESPR defines minimum requirements for the DPP's implementation, including a unique product identifier, interoperability with other systems, data accuracy and verification, and differentiated access levels. A backup copy must be securely stored by a trusted third-party provider, and the DPP must remain available throughout the product's lifetime.

3 *DPP - Basic requirements*

In industries like furniture, where materials and components often come from diverse sources, DPP-enabling technologies offer a robust framework for managing traceability. They facilitate compliance with EU legislation, including the General Product Safety Regulation (GPSR), the EU Deforestation Regulation (EUDR), and REACH, while enabling more sustainable product design and transparent communication with consumers.

It is important to note that more detailed information on the requirements of DPPs is expected to be released by the EU under delegated acts in the coming months.

In conclusion, the DPP is made possible by a technological ecosystem that connects physical products to their digital identities, making traceability not only feasible but central to future-ready, circular, and compliant supply chains.

Application

Imagine scanning a chair's QR code and instantly discovering where its materials come from, how it was made, how long it will last, and how to recycle it at the end of its life.

4 *DPP - Application to the furniture sector*

This is the promise of the Digital Product Passport (DPP) in the furniture sector. Designed to improve sustainability, transparency, and traceability, the DPP is becoming an essential tool for companies embracing circular economy principles and greater environmental responsibility.

5 *DPP - Traceability & Innovation*

6 *DPP - LCA & Circularity*

Material traceability and production transparency

With the DPP, every piece of furniture becomes a documented story. Materials can be traced back to responsibly managed or recycled sources, and their environmental footprint is made visible. A simple scan gives consumers access to sourcing details, supply chains, and production data. It also reveals how much CO_2 was generated during manufacturing and which components can be recycled or reused.

Certifications, standards and regulatory compliance

The DPP can include relevant certifications related to product quality, safety, and environmental performance, such as low-emission materials or fire resistance. In the context of evolving European regulations, the passport supports legal compliance, reduces risk, and enhances a company's credibility in sustainability reporting.

Product traceability in the furniture sector through the Digital Product Passport (DPP)

Measuring sustainability and environmental impact

Companies can use the DPP to monitor and communicate the environmental performance of their products. This includes data on energy consumption, carbon emissions, and circularity indicators such as recyclability or compostability. Making this information visible supports informed purchasing and reinforces the brand's environmental values.

Maintenance, warranty and product care

Consumers can easily access care instructions, manuals, and spare part details. Over time, repair history and maintenance records can be added to the passport, turning it into a dynamic tool for predictive maintenance. This helps extend the product's life and encourages repair instead of early replacement.

End-of-life management and recycling guidance

The DPP provides clear disassembly instructions and identifies materials, making it easier to separate components for recycling. This simplifies collection processes, increases recycling efficiency, and supports circular resource management.

Supporting circular design and reuse business models

By keeping a traceable digital record of a product's life, the DPP supports innovative business models such as leasing, buy-back programs, resale of used furniture, and refurbishing. The passport can be updated whenever a product is repaired or modified, preserving its value and usability across multiple lifecycles.

Engaging consumers through transparent information

Transparency strengthens consumer trust. The DPP offers instant access to verified information on product composition, origin, and sustainability. This empowers customers to make conscious, responsible choices and supports a shift toward more ethical consumption patterns.

Optimizing inventory and production planning

When integrated into digital systems like ERP platforms, the DPP improves data flow across departments. Accurate, real-time information on each product helps optimize inventory, align production with demand, and reduce waste in logistics and supply chain operations.

Implementation Aspects

Implementation difficulty: High

The implementation of the Digital Product Passport (DPP) in the furniture sector is uncertain and complex. It requires evaluating various technologies (e.g. blockchain, data service ecosystems), ensuring interoperability, and integrating the DPP into existing systems. Additional challenges arise from the structure of the sector: many small and medium-sized enterprises (SMEs) with varying levels of digital readiness, and a highly fragmented supply chain involving numerous suppliers and subcontractors. Effective access control, data security, and verification mechanisms are also essential.

Economic viability: Medium

The economic viability of the Digital Product Passport (DPP) in the furniture sector can be considered medium, as the initial costs-related to the adoption of new technologies, staff training, and IT system upgrades are significant, especially for SMEs. However, in the medium to long term, the DPP offers clear economic benefits: increased efficiency, access to sustainability-driven markets, enhanced brand image and waste reduction. Collaborative supply chain models and public incentives can further improve the economic sustainability of the initiative.

Human factors

The implementation of the Digital Product Passport (DPP) in the wood and furniture sector involves more than just technological innovation, it demands a human-centred transformation Workers play a central role in this transformation, and their ability to adapt, learn, and actively engage with new systems is a decisive factor for the DPP's success.

To meet these new demands, professionals must develop a wide range of digital skills. These include technological proficiency, awareness of data security, and a strong foundation in ICT tools, data handling, and digital documentation processes.

However, mastering technology is only a part of the equation.

The shift to digital processes also calls for soft skills like adaptability, analytical thinking, collaboration, and effective communication, which are critical for fostering alignment between digital workflows and real-worl

practices.A key human consideration is the need to promote a mindset of continuous learning.

As digital tools and systems evolve, workers must be supported through accessible training, mentoring, and peer-learning initiatives, especially those who may be less familiar with digital technologies.

Encouraging ongoing learning ensures that everyone can confidently participate in innovation rather than be left behind.

It's also important to address the emotional and psychological aspects of change. Digitalization can lead to uncertainty, resistance, or anxiety, particularly if the transformation feels top-down, overly technical, or disconnected from day-to-day needs. That's why building a supportive, inclusive organizational culture is crucial. Employees should be involved in the transition process, feel heard, and be given a sense of agency, recognition, and opportunities for grow.

Ultimately, the DPP's success depends not only on the tools introduced, but on how meaningfully individuals are trained, involved, and empowered to engage with them as part of their evolving role in the organization.

◼ Environmental factors

The introduction of the Digital Product Passport (DPP) in the wood and furniture sector marks a significant step toward greater environmental sustainability. This digital tool enables the collection, tracking, and sharing of detailed information on a product's life cycle from raw material sourcing to production, distribution, use, and end-of-life.

In this context, environmental factors play a central role, directly influencing how products are designed, manufactured, and disposed of.

Through the DPP, companies can monitor and report key environmental indicators such as carbon footprint, energy consumption, material recyclability, the presence of hazardous chemicals, and circularity levels. These data not only allow for a better assessment of a product's environmental impact but also encourage more responsible practices and eco-friendly design strategies.

Furthermore, the DPP promotes transparency and accountability across the entire value chain from manufacturers to consumers, enabling more informed and sustainability-oriented purchasing decisions. It also improves end-of-life management by providing easier access to information about materials and components, facilitating reuse, recycling, or proper disposal. However, the environmental sustainability of DPP systems themselves must also be critically evaluated, considering the digital infrastructure, data management, and hardware dependencies that support their implementation.

DPPs rely on product-specific identifiers, such as RFID tags, QR codes, and embedded IoT sensors, which are linked to cloud-based databases and blockchain or centralized information systems. The manufacture of these digital identifiers and tags involve plastics, silicon-based chips, antennas, and in some cases, batteries. This raises concerns about resource use, electronic waste, and toxic materials, especially when DPPs are deployed at scale across millions of products.

Moreover, the data infrastructure underpinning DPPs, such as servers or cloud platforms, introduces significant resource use and energy and water demands. Blockchain-based DPP systems, while offering transparency and data immutability, have been criticized for high energy intensity. Even cloud-based or hybrid approaches involve continuous data transmission, storage, and security operations, which contribute to the environmental impact of digital supply chains.

◼ Alignment with certifications and regulations

The DPP in the furniture sector must align with EU regulations such as the **Ecodesign for Sustainable Products Regulation (ESPR)**, **REACH Regulation (including formaldehyde restrictions)**, the **General Product Safety Regulation (GPSR)**, the **EU Deforestation Regulation (EUDR)**, and **Green Public Procurement (GPP)** criteria.

CE marking may apply depending on product type. Voluntary schemes like **FSC, PEFC, EU Ecolabel**, and **EPDs** support transparency and are valuable when integrated into the DPP for sustainability and compliance communication.

References to EU regulations:
· Ecodesign for Sustainable Products Regulation (ESPR): 🔗
· REACH Regulation (including formaldehyde restrictions): 🔗
· General Product Safety Regulation (GPSR): 🔗
· EU Deforestation Regulation (EUDR): 🔗
· Green Public Procurement (GPP) criteria: 🔗

THE DIGITAL PRODUCUT PASSPORT IN THE FURNITURE SECTOR

Authenticity · CO₂ Carbon · Sustainability · Recyclability · DIGITAL PRODUCT PASSPORT

How the Digital Product Passport supports traceability and innovation in furniture sector

Reliable data on materials and sourcing
Access to structured information on new materials, production methods, and origins

Transparency for consumers
Easy access to verified product data that supports informed and responsible choices

Full traceability across the value chain
Secure-tracking of lifecycle stages and components for every furniture product

Enabling circular practices
Facilitates reuse, refurbishment, and recycling through smart design and data continuity

New business model opportunities
Enables leasing, take back programs and second-life marketplaces

Smarter production and logistics
Integration with digital systems (e.g. ERP) to optimize inventory and reduce waste

6

How the Digital Product Passport connects lifecycle phases and supports circularity

Product Design

Data flow

DIGITAL PRODUCT PASSPORT

Raw materials

Production

Reuse, recycling

Matei flow

Auto-maintenance

Use & Maintenance

End-of-Life

Use

Data flow

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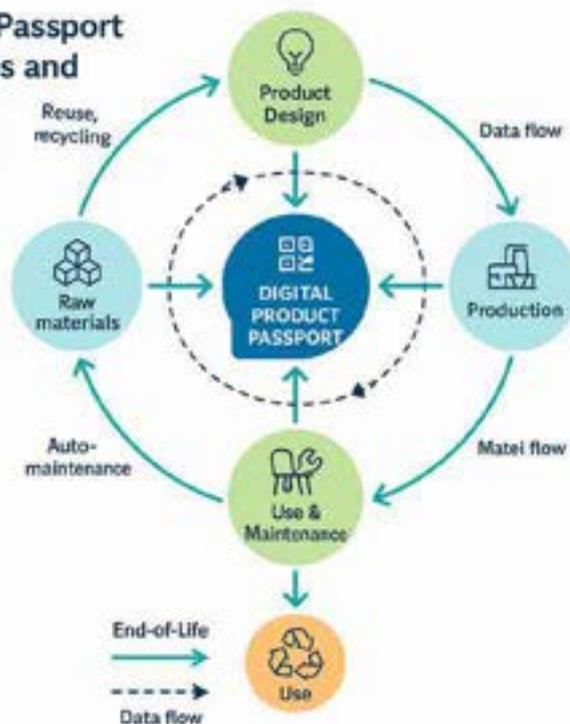
Product traceability in the furniture sector through the Digital Product Passport (DPP)

Solutions

Blockchain
EZ Lab
Italy ⊂⊃

EZ Lab developed the Made in Block platform to create digital passports for furniture products, using blockchain technology to ensure traceability and immutability of data throughout the production chain. Scanning a QR code on the product provides access to details on production, raw material origin, and sustainability certifications, ensuring transparency and supporting preparedness for future compliance with the ESPR (Ecodesign for Sustainable Products Regulation).

QR corde
ScanTrust
Switzerland ⊂⊃

ScanTrust offers a QR CODE-based solution to support the implementation of the Digital Product Passport (DPP). The platform enables manufacturers to link each product to a dynamic, secure and traceable QR CODE that connects to a digital profile containing detailed information on material origin, sustainability, production process, usage instructions, repair, reuse and recycling.

NFC (Near Field Communication)
Smartrac (Avery Dennison)
Netherlands ⊂⊃

Smartrac, part of the Avery Dennison group, offers NFC (Near Field Communication) solutions to track products and enhance consumer interaction. Their NFC technology is used to create personalized experiences and provide detailed information about products, such as their origin, authenticity and sustainability data. NFC tags allow consumers to easily interact with products via smartphones, accessing exclusive content or additional information simply by bringing their device close to the product.

Cloud-based platform
WOOD.BE
Belgium ⊂⊃

WOOD.BE, in collaboration with TripleR.io, is developing FurniPASS, a digital product passport tailored for the furniture sector. Part of the Belgian "BBBC 2023" initiative, the project aims to create a working prototype aligned with upcoming ESPR requirements. FurniPASS targets stakeholders across the value chain (manufacturers, recyclers, consumers, and institutions) and includes activities such as supply chain mapping, eco-design guidelines, and testing in a demo environment. The project runs from 2024 to mid-2026 ⊂⊃

Digital Twin
HARTING
Germany ⊂⊃

More areas of life are being electrified, and sectors are being intelligently interconnected. To achieve true climate neutrality, companies must also critically examine the components of their products. This is where HARTING comes in: the digital twin is the key to determining the sustainability information of a good in the context of digitization. The DPP enriches the digital twin with comprehensive data on each product component and makes it traceable.

Examples

Tonin Casa
Italy

Tonin Casa, an Italian furniture brand with over 45 years of experience, has adopted a Digital Product Passport integrated with blockchain technology to enhance transparency and traceability. This initiative supports the company's commitment to authentic Made in Italy craftsmanship and prepares for upcoming EU sustainability regulations. During the Salone del Mobile, products like the Lisa chair showcased their full production journey via QR codes, allowing users to access detailed information on materials, safety, and origin.

System 180 GmbH
Germany

System 180 is a German company that designs and manufactures furniture for contemporary work and living spaces. As part of the now completed project "AI-supported Object Detection for Increasing Resource Efficiency", the company contributed to the development of a circular economy model by improving resource efficiency in furniture production. The project focused on implementing computer vision technologies for the detection and classification of furniture components and their conditions. A key outcome was the integration of this object-level data into the Digital Product Passport (DPP), enabling more accurate traceability, improved reuse potential, and enhanced data-driven decision-making across the product lifecycle.

NORNORM
Denmark

NORNORM is the tech-driven circular furniture rental service that minimizes resource waste with adaptable solutions for the evolving needs of workspaces. NORNORM's Circular Passport utilizes QR codes on each furniture item, granting users access to product specifications, carbon footprint data, and the item's usage history, as well as reporting issues. This tool enhances customer service by enabling issue reporting and supports the company's commitment to circularity through transparent lifecycle tracking.

AkzoNobel Protective Coatings
Netherlands

AkzoNobel Protective Coatings has introduced a secure traceability solution to combat counterfeiting and improve digital communication with customers. Each paint container features a unique, secure QR code that enables instant verification of product authenticity via smartphone. Upon scanning, users are directed to a dedicated digital space where they can access region-specific product datasheets, safety documents, and application instructions. A centralized dashboard tracks interactions in real time, offering insights into customer behavior and preferences. By shifting from paper-based to digital documentation, the system not only enhances transparency and user experience but also reduces environmental impact and supports regulatory compliance.

R-evolve EU Project
Italy

R-evolve is a Horizon Project – funded by the EU that aims to accelerate the transition to a circular economy in the European furniture sector. The initiative seeks to integrate circular business models, sustainable design, the use of bio-based or recycled materials, and digital tools such as the Digital Product Passport (DPP). "R-evolve" engages the entire furniture supply chain, including private, business, and public consumers, and implements nine pilot projects with manufacturers, retailers, and service providers across Europe to test the proposed innovations.

To ensure lasting impact, "R-evolve" plans to develop practical guidelines, training materials, and a Community of Practice to facilitate knowledge sharing and the exchange of best practices on circular transition among the various stakeholders in the supply chain, coordinated by FederlegnoArredo.

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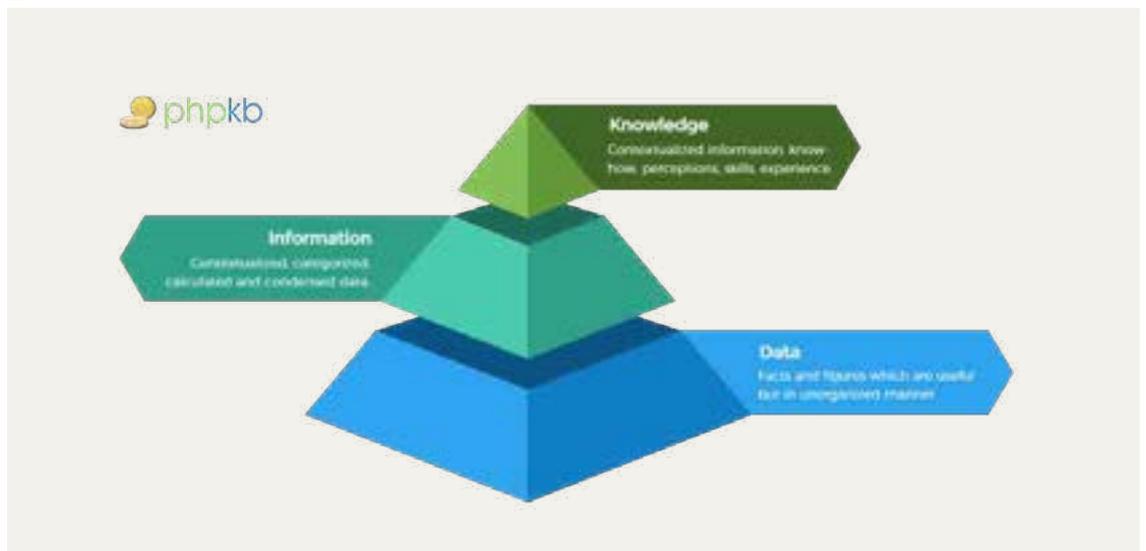
Implementation difficulty**: Low-Medium**
Economic viability: **Medium-High**

Data Science applied to Furniture Manufacturing

Description

Data science refers to the analysis of data to extract knowledge that can be used by companies to make data-driven decisions. Nowadays, companies generate large amounts of data at every stage of the process: from the early stages of product design to manufacturing, and through every interaction with customers and suppliers. The analysis of this data can help businesses gain insights on their processes and improve their performance, make informed business decisions and drive innovation.

[1] *Data to knowledge path* 🔗

Some of the data generated by companies in the furniture manufacturing industry include: supply chain data, product design and materials, production costs, sales and customer data. Besides, IoT technologies can gather additional real-time information such as environmental information (temperature, noise levels, pollution or air quality) or monitoring of the manufacturing process (energy or water consumption, machinery use and status, detection of faults and errors and efficiency metrics).

[2] Cloud-based manufacturing system architecture

Through the appropriate analysis techniques, meaningful information can be extracted from data. It must be noted that, regardless of the type of analysis applied, it is important to ensure the quality of the input data, which must meet the following characteristics: accuracy (how correct or error-free the data is), completeness (amount of data that is correct or complete), reliability (consistency of the data with other trusted sources), relevance (whether the data is useful and appropriate for the task) and timeliness (the data is up-to-date).

Once the data quality has been ensured, its analysis can assist the companies' decision making in many different areas. Depending on the desired output, different analytical techniques may be required. These techniques can include statistical analysis, data processing, data visualization or artificial intelligence algorithms.

[3] *The conceptual framework for furniture intelligent manufacturing based on big data-driven technology (Source: author)*

The furniture manufacturing sector can be benefited from data processing through all its life-cycle: designing and developing new products aligned with customers' trends and needs, measuring the effectiveness of campaigns, and better understanding customers' behaviour and preferences for more effective customer engagement and retention strategies; forecasting supply and demand, enabling production planning driven by customer demand and optimising logistics and transportation of products; ensuring manufactured product quality through real-time monitoring of the manufacturing process; applying fault detection algorithms to anticipate machine failures and prevent breakdowns, leading to predictive maintenance; or reducing energy

[2]
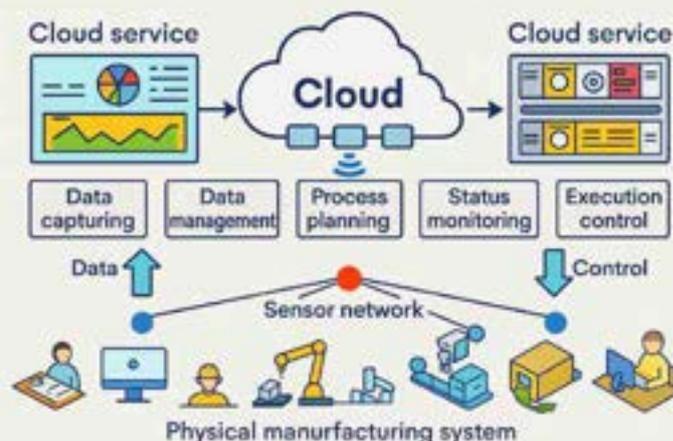
consumptions through energy management algorithms, re-scheduling and optimisation processes.

Beyond optimizing operations and product design, data can also be leveraged to improve workforce development through **data-driven training**. This approach represents another strategic application of data science within organizations. By analysing employee performance metrics, work analysis data, financial constraints, and stakeholder input, companies can design training programs that are targeted, efficient, and aligned with business goals. Data-driven training allows human development teams to identify skill gaps, monitor progress in real time, and evaluate the effectiveness of training interventions. It is not just about better content, it's about smarter, evidence-based decisions that connect learning outcomes directly to business performance.

Application

As indicated above, there are many ways in which data processing technologies can be applied in the furniture sector. Data-sources available can be combined and exploited through diverse techniques and provide the companies with improvements in different areas. These developments include:

· Applications aimed at **optimising the operative efficiency of the manufacturing process** through IoT-based monitoring, data analytics and automations. These technologies can be used for continuous and detailed supervision of production processes, anomalous behaviour detection, industrial cybersecurity improvement and predictive maintenance strategies establishment

to minimise downtimes, increase productivity and quality, and reduce maintenance costs and waste.

4 *Types of of maintenance (Source: ⊝)*

· Applications for optimizing **manufacturing and distribution supply chain**. Sale forecasting is crucial for anticipating demand from final customers and commercial clients. Data analytics can identify top-selling products, market trends and customer behaviour in order to forecast this future demand. Information coming from ERP systems and sales policies can also be analysed to identify customer trends. For these forecasts to be precise, they require the collaboration between the sales, marketing, operations and logistic teams. Once they have been obtained, the forecasts can be applied for the optimisation of inventories – avoiding both shortages and inventory excesses -, and the minimisation of manufacturing costs. In combination with predictive maintenance of the equipment and quality control applications, potential issues can be identified to **prevent delays**. In a similar way, when combined with route optimisation algorithms, they can help optimising **logistics and delivery**, minimising transportation and distribution costs.

5 *Supply-chain planning through predictive analytics*

· Applications related to **sustainability and waste reduction** which include data processing to automatically assess the environmental impact associated to the different stages in the products' life cycle, or the carbon footprint of the products. They can also refer to an analysis of the waste generation patterns, identifying opportunities to reduce waste and increase recycling.

· Applications related to **quality control and inspection**, based on image and sensor data, processed through Machine Learning (ML). These technologies can help detect irregularities and defects in products automat-

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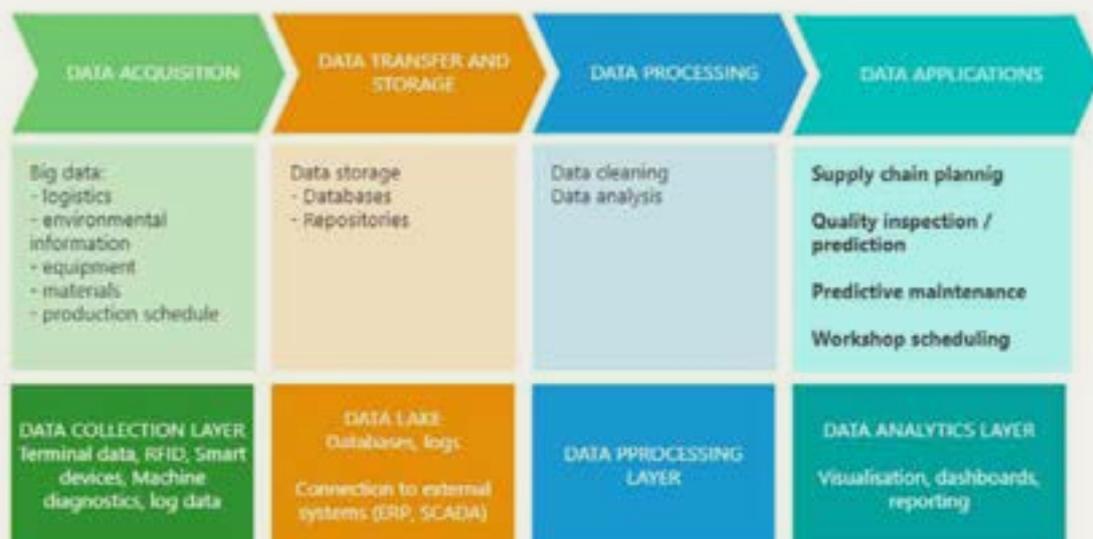
ically, ensuring product quality before its distribution.

6 *Schematic diagram of defect detection system*

- Applications related to the **design and prototyping of products**. **Generative design algorithms** can assist designers with the generation of multiple options based on instructions and rules established by designers, providing new modelling approaches. The technologies also allow generating new designs based on previous ones, based on nature, using complex shapes or modelling customised products. They can provide a wide range of results, allowing the modification of parameters such as materials, dimensions or functionality.
- Application for **marketing and customer experience improvement**. Data analytics can be applied to customer profiles to make personalised product recommendations, tailor marketing campaigns and generally improve customer service. Natural Language Processing (NLP) and chatbot technologies offer the possibility to provide 24/7 customer support.

Implementation Aspects

■ **Implementation difficulty: Low/Medium**

Given the wide nature of solutions related to data processing in the manufacturing, it's hard to assess their implementation difficulty. Overall, there are stable technologies that provide good solutions for improving different aspects of the process with low difficulty. If the solution involves Artificial Intelligence algorithms, one of the main difficulties lies on providing the system with enough accurate data for training the algorithms.

■ **Economic viability: Medium-High**

The cost related to the solution deployment will depend on software licenses, development or customisation costs, and especially on the varying hardware needs (which can range from low-cost IoT devices to robotics or automated machinery). In each case, an economic viability analysis must be carried out to assess the economic benefits and cost reductions achieved (through the optimisation of maintenance, stock minimisation, etc.) and calculate the Return of Investment of the deployment.

■ **Human factors**

Data processing technologies can raise certain concerns among the workers, such as fear for their jobs, and issues related to privacy. Workers may fear that these new technologies, such as automation or artificial intelligence, will put their jobs at risk. However, these technologies can also create new job opportunities, like the operation and maintenance of new machinery or

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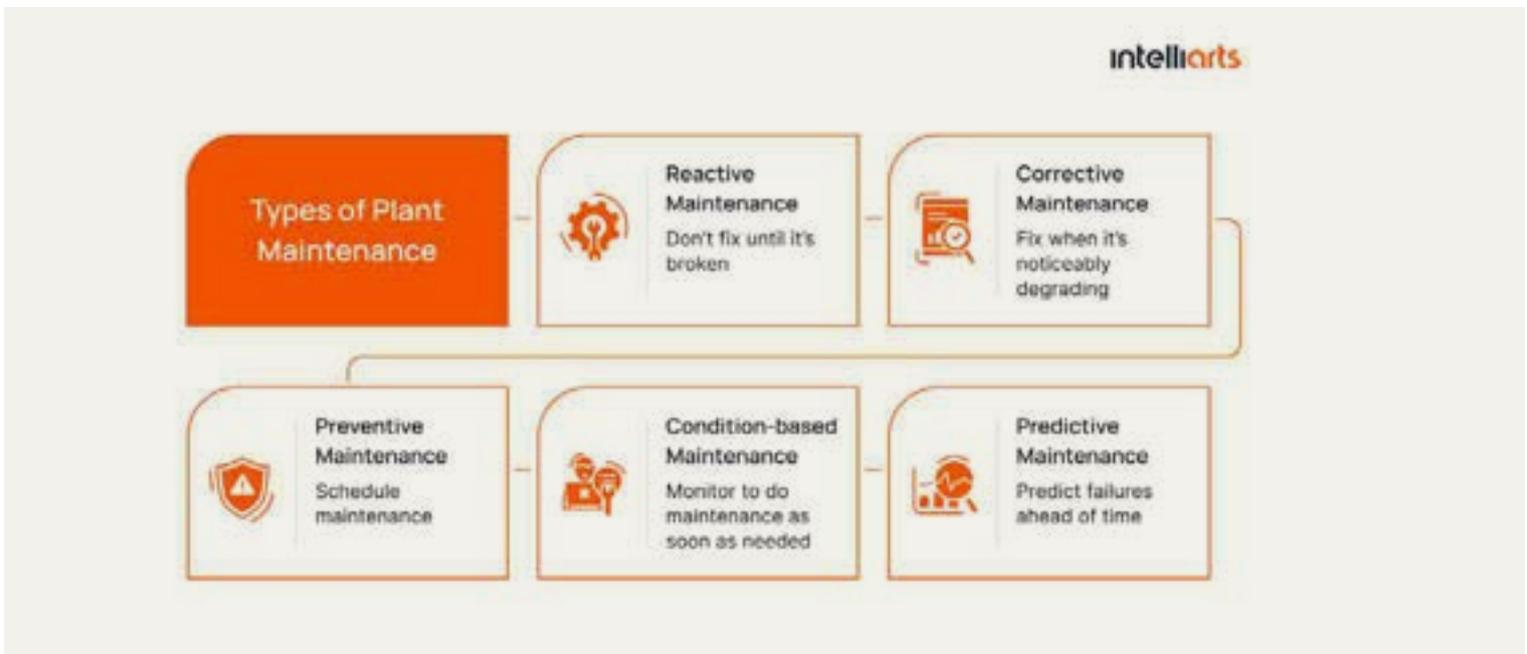
understanding and taking advantage of data analytics. To foster a smooth transition, it's crucial to proactively communicate that these tools are designed to support—not replace—human expertise. Training programs can help workers adapt to the new opportunities and mitigate job displacements.

Regarding privacy, the use of data analytics involves gathering and processing large amounts of data, which may include personal information of the workers. Ensuring that the collected information is handled ethically and in compliance with privacy regulations is vital. A clear understanding of what information is being collected, how it is going to be used, and the purpose of such analysis will also be beneficial for the acceptance of these solutions. Transparency, informed consent, and compliance with GDPR are essential pillars of ethical data governance.

At the same time, data processing technologies can also improve working conditions by enhancing their safety through predicting potential hazards and preventing accidents through monitoring of the installations. They can also improve ergonomics and reduce physical strain by automating or optimising high-risk or repetitive tasks.

In summary, the successful implementation of data processing technologies depends not only on technical deployment, but also on building digital confidence, safeguarding worker rights, and embedding human-centred design across systems and workflows.

Environmental factors

There are several environmental factors that support the adoption of data processing technologies in the sector.

For instance, these technologies can bring an improvement in the efficiency of the resources consumed. Data processing technologies have the capacity to optimise the use of materials, reduce waste and minimise the carbon footprint of manufacturing processes. The analysis of production data allows the identification of areas in which resources can be used more efficiently. Furthermore, monitoring of machinery and production plants allow a better management of energy consumptions, increasing their efficiency, and reducing greenhouse gas emissions.

These technologies also support the implementation of eco-design, assessing the impact of the different processes through the whole lifecycle of products and materials, and of circular economy principles, tracking them throughout the supply chain and facilitating their recycling and upcycling processes. Waste can also be managed more efficiently through the identification of sources and types of waste generated, for its optimised recycling and disposal activities.

Last, data processing technologies can assist manufacturers in their compliance with environmental regulations, simplifying and automatically generating reports on diverse environmental metrics and indicators, and supporting the environmental certification processes and the adherence to industry standards.

However, at the core of data processing lies a physical infrastructure of servers, storage devices, networking equipment, and cooling systems, mostly located in centralized or edge data centers. These facilities require significant electricity and water to operate, not only to power computing tasks but also to maintain cooling and ensure redundancy. The hardware manufacturing phase also carries a substantial environmental cost during mining and refining of the used materials (metals, rare earth, etc.) and components (electronics, etc.). Additionally, rapid obsolescence cycles in IT hardware (often 3–5 years) exacerbate e-waste generation, much of which is not properly recycled due their complexity.

One of the most energy-intensive applications of data processing is AI and machine learning, but growing impact area is data storage and redundancy. This stored but unused information contributes to server loads and energy consumption without adding value.
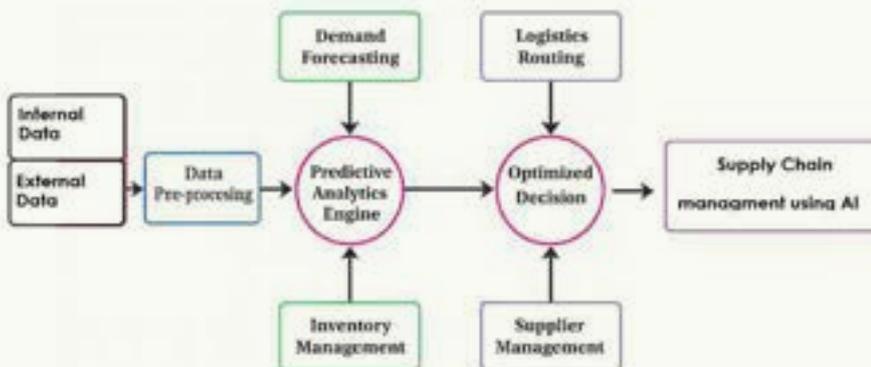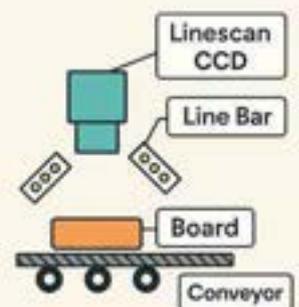
■ Alignment with certifications and regulations

Alignment with certifications and regulations

There are several regulations and certifications that apply to the furniture manufacturing industry and that can be linked to the data processing technologies. For instance,

- They can help manufacturers comply with environmental certifications and regulations such as EU's Sustainable Products Regulation (ESPR ⊖) and generate Digital Product Passports (DPP)
- General Data Protection Regulation (GDPR ⊖) must be considered when managing customers' or workers' information.
- Cybersecurity standards help keeping data integrity and preventing security breaches. (ISA/IEC 62443 Series of Standards - ISA ⊖) (NIS2 Directive: new rules on cybersecurity of network and information systems | Shaping Europe's digital future ⊖) (Cyber Resilience Act | Shaping Europe's digital future ⊖).

Data Science applied to Furniture Manufacturing

Solutions

Predictive maintenance of industrial machinery
DRIBIA
Spain ⌐⊃

Machine learning based anomalous behaviour detection in machinery with the objective of increasing productivity, reducing waste, improving product quality, and reducing time and costs associated with repairs, maintenance, interruptions and machine shutdowns. The system can identify conditions that are non-optimal or may lead to machine shutdowns.

Warehouse management system
TESY software
Italy ⌐⊃

TLog is a WMS software that controls all the fundamental entities in the warehouse environment. It monitors acceptance, loading and delivery of products, improves warehouse management performance with intelligent product and location labelling, manages priorities and speeds up processes and maximises operators' efficiency through guiding when picking up materials.

Supply-chain optimisation
AIMMS
The Netherlands ⌐⊃

The SC Navigator application for supply network design allows the visualisation of the current supply chain, optimisation of flows and scenario simulation considering changes in demand, disruptions in locations and modes of transport. The tool aims to optimise costs, service levels and carbon footprint.

On-demand manufacturing and supply chain automation
Lectra
France ⌐⊃

Lectra offers Furniture On Demand, an end-to-end solution for automating production and supply chain processes in the furniture sector. It connects cutting room components, automates workflows, and enables data-driven decision-making to enhance efficiency and growth. The platform supports customization and sustainability by optimizing material usage and enabling flexible, on-demand manufacturing.

Real-time data preprocessing and interconnectivity
Node-RED / Flowfuse
United States ⌐⊃

Node-RED / Flowfuse addresses key industrial IoT challenges by providing a visual, flow-based environment that simplifies integration, management, and automation of connected devices. It enables seamless data collection from diverse sensors, real-time analytics at the edge, protocol translation, and secure cloud connectivity—empowering rapid development of scalable and maintainable solutions.

Data-driven training for personalized learning
Rapl
United States ⌐⊃

Rapl is a data-driven training platform designed to accelerate workforce development through personalized, performance-based learning. By leveraging algorithms and analytics, it identifies skill gaps and delivers targeted content tailored to individual needs. L&D managers gain real-time insights into learner progress, enabling precise, impactful interventions. Rapl transforms corporate training from passive presentations into dynamic, measurable learning experiences. The result: faster skill acquisition, improved performance, and a future-ready team.

SIMON
Spain

GOIA is a tailor-made tool for customer demand prediction. It combines prediction with AI, using "analyst in the loop" tools to take into consideration the experience and judgement capabilities of the operators. This improves the quality and confidence in the results, as well as the capability to adapt to unexpected issues.

Blum
Austria

Blum produces hinge-, lift- and runner-systems and the appropriate assembly tools for the cabinet making and furniture industry. Craftsman developed a Big Data infrastructure for multiple use cases in predictive analytics and quality assurance for a better, data-driven decision-making process, production planning and supply chain relevant insights.

ABI Mouldings
Canada

MRPeasy inventory Management soluiton helped ABI Mouldings to accommodate a roughly 75% increase in production volume over the span of around two years. The app proved to be a crucial aid in both supply chain, order, and inventory management, and for planning ahead production.

IKEA
Sweden

IKEA Kreativ uses AI and spatial computing to transform user photos into editable 3D room models. It enables personalized product visualization, supports generative design for interior planning, and enhances customer experience and marketing effectiveness, reducing waste from physical prototyping and aligning with digital customization trends.

Unilin (+ Robovision)
Belgium

Unilin Group uses AI-powered vision systems to detect subtle defects in laminate plates at high speeds (100/min), automating quality control, increasing yield, and improving efficiency. Deep learning models continually improve by learning from new defect and pattern data, are easily retrainable, and support scalable deployment across varying products and lines.

Amcor
Switzerland

Amcor, a global leader in developing and producing responsible packaging, was already capturing a lot of data from its 23 facilities with a traditional SCADA system. But a lack of visibility, standardization, and automation meant the company wasn't getting enough value out of that data. In order to drive better line performance, Amcor built a manufacturing execution system suite at the edge using AVEVA System Platform to enable teams to consistently measure and track production data. It is a great example of how to make better use of collected data by transforming it into meaningful insights.

Human-machine interoperability

Implementation difficulty: **Low/Medium**
Economic viability: **Medium-High**

Human-machine interoperability

Description

The digitalisation of the manufacturing industry involves technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and Big Data. For companies to take full advantage of the opportunities brought by these technologies, agile and user-friendly interfaces must be implemented.

[1] *Touch screens for manufacturing. Creator: Leif Juergensen | Credit: Leif Juergnesen Copyright: Leif Juergensen.*

The deployment of this digitalisation presents several challenges:

- **Connectivity:** the environment presents heterogeneous data sources including devices, machinery or legacy systems, which results in the need to combine different protocols and formats to allow interoperability. To address this challenge, interoperability standards and enabling technologies such as OPC UA (Unified Architecture), MQTT, LwM2M and REST APIs play a critical role.

- **Cost:** digital transformation entails important initial investments in technologies, software licenses, infrastructure, developments and specialised workforce.

- **Scalability:** digital systems must be able to cope with growing demands –in terms of requirements, data or processing loads-.

- **Interaction with humans:** HMIs and visualisation technologies are fundamental for the digital transformation of organisations, being the connection point between users and technologies. The reliability of these HMIs should be guaranteed (through redundancy, fail-safe mechanisms, UI/UX design principles) for consistent and error-free interactions in critical workflows.

- **Cybersecurity:** as systems become increasingly interconnected, they become more vulnerable to data breaches, unauthorised accesses, or system disruptions. Cybersecurity standards (as ISA/IEC 62443 (ISA/IEC 62443 Series of Standards - ISA ⊖), NIS2 directive (NIS2 Directive: new rules on cybersecurity of network and information systems | Shaping Europe's digital future ⊖), or Cyber Resilience Act (Cyber Resilience Act | Shaping Europe's digital future ⊖)) allow mitigating these risks and securing both data and systems.

In this last aspect, Industry 5.0, built on digitalisation technologies, presents a more human-centric approach, with three basic pillars: safety, reliability, and human-centred design. The objective is to facilitate the intelligent collaboration between humans and machines, combining human intelligence and creativity with efficient, intelligent, and precise machines.

[2] Industry 5.0 pillars

According to the European Union, Industry 5.0 "provides a vision of industry that aims beyond efficiency and productivity as the sole goals and reinforces the role and the contribution of industry to society". It also " places the wellbeing of the worker at the centre of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the limitation of planet resources."

In relation to HMIs and the interoperability between humans and technologies, the interfaces must be designed to be intuitive and user-friendly. Operators must be able to interact seamlessly with increasingly complex systems. User experience (UX) and User-Centered designs (UCD) put users at the centre of the interface design. For instance, agile UX frameworks enable rapid adjustments in the design based on user feedback, allowing operators to be involved in the HMI design phase. These operator-centric designs minimise the learning curve, reduce training time and increase workers' productivity.

In the case of monitoring and control of manufacturing processes, HMIs provide operators with real-time insights into machine, production line or system operations. Visualisation software ensures that all the data that is being collected is presented in an intelligible, comprehensive and actionable format. These visual interfaces can incorporate AI algorithms to assist operators in their decision-making processes, analysing big amounts of data and providing insights that, combined with their expertise, can be used by operators to make the final decisions.

[3] *Human-machine interaction: robot behaviour programming*

Finally, regarding the ergonomic design of interfaces for ensuring the comfort and safety of workers, there is a wide range of physical interfaces that can be applied to reduce physical strain, such as touchscreens, voice commands, and gesture controls. These technologies also promote accessibility and inclusiveness in the workforce by accommodating users with visual, motor or auditory impairments, ensuring equal access to digital systems.

Human-machine interoperability

Using the right visualization and HMIs platforms can improve the efficiency, safety and productivity of the manufacturing process.

Collaborative design

In the context of Industry 5.0 and human-machine interaction, collaborative design plays a key role in developing intuitive and efficient HMIs. This approach involves multiple agents working together in real time to co-create interfaces that are functional, ergonomic, and aligned with user needs. By sharing expertise and feedback throughout the design process, teams can ensure that the resulting systems support productivity, safety, and user satisfaction.

[4] *HMIs for collaborative design ⊖ Source, creator and credit: rawpixel ⊖ License details ⊖*

Real-time and historic monitoring

During the production process, HMIs can minimise downtime and optimise production efficiency. In scenarios where minimising the latency is critical, integrating Edge Computing technologies enable faster decision-making. They allow real-time data visualisation - monitoring machinery performance or tracking production metrics - and control of the machinery - adjusting settings as needed -. The visualisation of relevant data - collected by monitoring systems, and processed by data analytics algorithms -, presented to operators in a user-friendly and comprehensive format allows them to follow the production process correctly, act upon the presented information and make informed decisions. This information can be applied to:

· Improving the efficiency of the manufacturing process.
· Reducing the waste generated during the manufacturing process.
· Performing quality control operations and detecting defects early in the process.
· Identifying bottlenecks and optimising production workflows, for an improved efficien-

cy of the operations and reduced downtime.
· Monitoring and managing energy consumption, contributing to more sustainable manufacturing practices and reducing the carbon footprint of operations.
· Performing remote maintenance operations based on alarm and issue notifications, and the integration of chat tools and screensharing capabilities, to allow the collaboration between on-site operators and remote technicians for rapid solving of issues.

Human-Robot Collaboration

HMIs facilitate collaboration between humans and robots (Human-Robot Collaboration, HRC) by providing interfaces that allow operators to easily program and control robotic systems. The objective is not replacing human workers, but emphasizing the importance of cooperation and complementarity by leveraging their respective strengths. On one hand, humans can apply experience-based reasoning, react to unexpected issues, and make judgements based on incomplete or ambiguous information. Physically, humans can handle complex and precise manual tasks, as well as those that require craftsmanship. On the other hand, robots and machines can perform heavy tasks, operate continuously and execute repetitive tasks with consistent quality. Besides, they can work in hazardous environments, such as toxic environments or under extreme temperatures. Nevertheless, HRC entails several challenges, including safety risks end ergonomics. A safe interaction must be ensured when robots and humans share the same space, through position monitoring, collision avoidance, emergency stops and protective measures. Intuitive and ergonomic interfaces must also be designed, to minimise fatigue, reduce risks and enhance user comfort.

[5] *Dependencies in human-robot collaboration. License details ⊖. Creator: Jeshwitha Jesus Raja, Meenakshi Manjunath, Philipp Kranz, Fabian Schirmer, Marian Daun. Copyright: © 2023 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0) ⊖*

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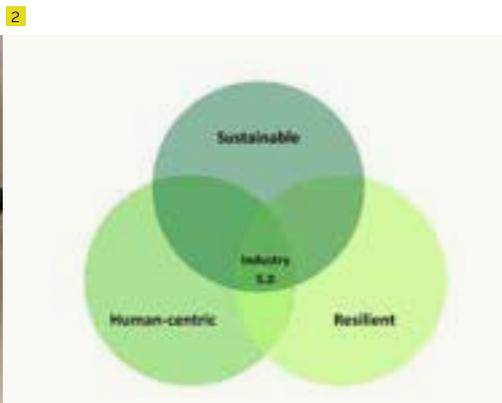
Training and skill development

Intuitive HMIs minimise the learning curve and facilitates new operators' use of complex machinery through interactive touchscreens, visual aids, and step-by-step instructions. They can also incorporate interactive tutorials and simulations that provide hands-on training experience. Virtual environments can be set-up for practices, before the operators handle the real equipment, increasing their confidence. HMIs can also track the operators' performance during training, identifying areas that need further development.

6 *Virtual reality simulation*

Implementation Aspects

■ **Implementation difficulty: Low/Medium**

The implementation difficulty of HMIs for the furniture industry is low when considering solutions already available in the market, as the design of user-friendly interfaces for operators to control complex machinery. For applications closer Industry 5.0, however, there are still several challenges to face: development maturity and deployment costs of technologies, human-centric design of products and processes, workers' current skill levels or security issues brought by the personalisation of HMI analysis and increased data collection.

■ **Economic viability: Medium-High**

The economic viability of HMI development for the furniture industry depends on the type of solution and their associated investments costs, which will vary greatly – especially when considering the purchase of new hardware components-. Nevertheless, new HMI solutions can enhance productivity and efficiency of the manufacturing process, helping to overcome these ini-

tial costs. For that reason, the decision-making process requires careful financial planning and an analysis of the return of the investment.

■ **Human factors**

A central tenet of Industry 5.0 is placing humans at the heart of technological progress through intuitive interfaces, assisted monitoring, and improved ergonomics, comfort, and safety. Human-Machine Interfaces (HMIs) provide multiple advantages, creating more accessible and less demanding work environments. They ease onboarding, reduce learning curves, and support the recruitment of digitally competent talent. Existing personnel can enhance their skills through training in digital interfaces, data interpretation, and collaboration with automated systems.

Although concerns may arise that robotics and new machinery could reduce staff, the aim of Industry 5.0 is not replacement but meaningful collaboration between human capabilities and machine precision. This synergy allows organisations to combine creativity and judgement with automation's consistency and speed, optimising operations and contributing to sustainable, human-centred production environments.

■ **Environmental factors**

In furniture manufacturing, HMIs offer environmental benefits. They optimise machinery, lowering energy use and carbon footprint, while enhancing precision, control, and maintenance efficiency, which reduces waste. Improved data collection and analysis also help monitor impact and ensure compliance with regulations. Together, these practices support sustainable, responsible production.

Challenges remain. HMI hardware includes displays, sensors, processors, cameras, and sometimes biometric or neural devices. These rely on rare earths, precious

metals, and engineered plastics, whose extraction consumes high energy, emits pollutants, and is difficult to recycle. Manufacturing often involves cleanrooms, precision fabrication, and multilayer circuits, all resource-intensive. As HMIs grow more sophisticated, repair, reuse, and recycling become harder.

Operationally, HMIs consume modest energy compared with data centres or robotics, but integration into always-on systems creates continuous standby use. Voice and vision-based HMIs often depend on real-time processing and cloud-based AI, linking their footprint to external infrastructure like data centres.

Another concern is short lifespan and high replacement rates, especially in consumer electronics such as smartphones, tablets, and wearables, often replaced every 2–3 years. Non-modular designs hinder disassembly and recovery of valuable materials, adding to e-waste.

Balancing the human and environmental benefits of HMIs with their material and energy costs is essential. Sustainable design, longer lifecycles, and circular practices can maximise the role of HMIs in advancing Industry 5.0 while promoting environmental responsibility.

■ Alignment with certifications and regulations

There are several regulations and certifications that apply to HMIs deployed in the furniture manufacturing process, as, for instance:

· Storage and treatment of personal information by HMIs must comply with the General Data Protection Regulation(GDPR ⊖).

· HMIs must also comply with cybersecurity standards and regulations to ensure data protection and prevent security breaches (as ISA/IEC 62443 (ISA/IEC 62443 Series of Standards - ISA ⊖), for securing industrial control systems; NIS2 directive (NIS2 Directive: new rules on cybersecurity of network and information systems | Shaping Europe's digital future ⊖), EU's critical infrastructure regulation; or Cyber Resilience Act (Cyber Resilience Act | Shaping Europe's digital future ⊖), cybersecurity standards for digital products sold in Europe).

Human-machine interoperability
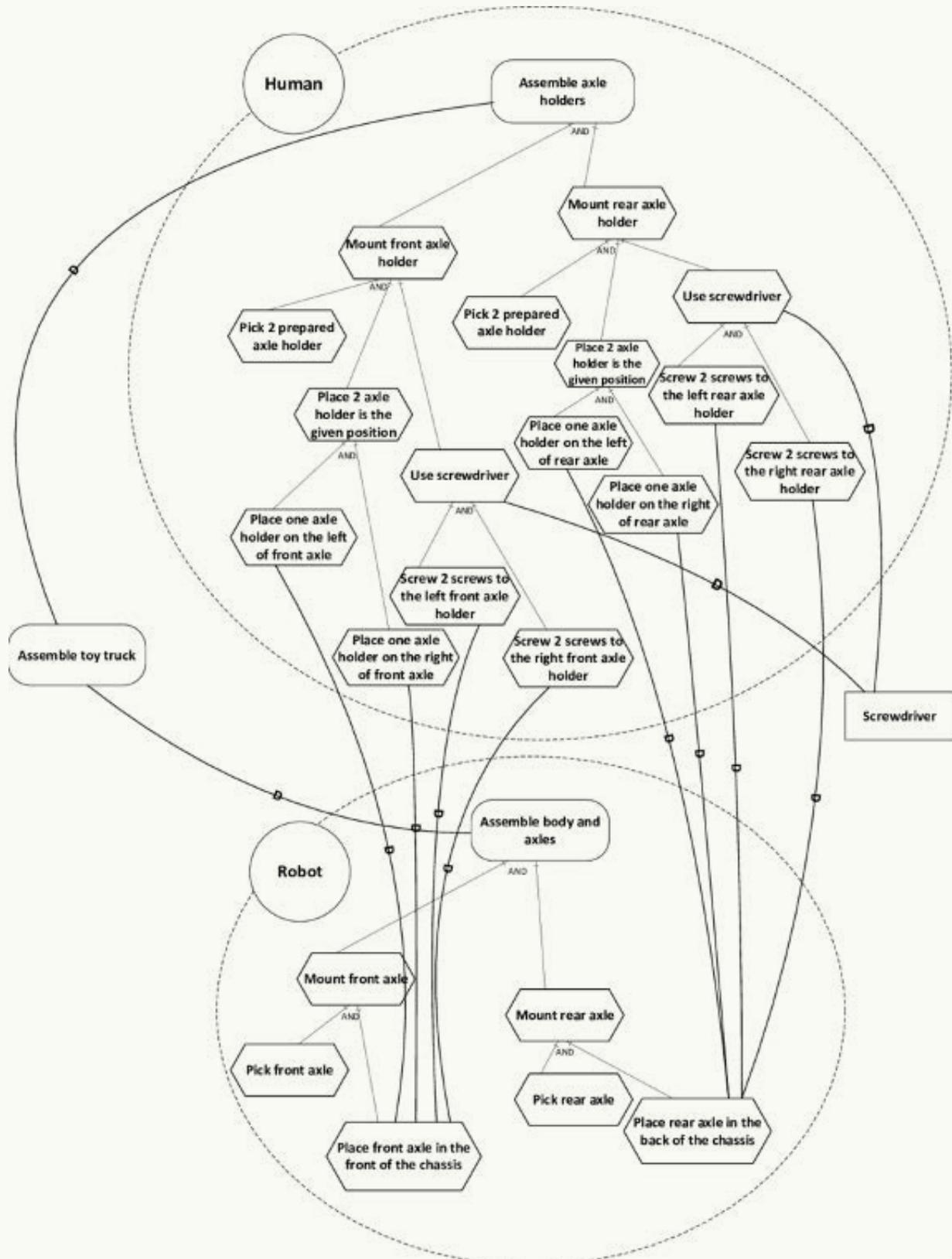
Solutions

Schneider Electric Human-Machine Interfaces
Schneider Electric
France ⊖

Easy to install, configure and operate, Schneider Electric HMIs provide a simple and efficient way to connect systems, gather data and present information in an understandable way. Suitable for industries such as furniture manufacturing, they offer a wide range of solutions, from the smallest graphical terminals to industrial PCs.

HMI/Scada System
Beijer Electronics
Sweden ⊖

Advanced HMI solutions for enhanced user experience, scalable automation systems for efficiency and cost reduction, and robust digitalization tools, ensuring long-term value and adaptability across industries. They offer customisable iX-based solutions for industrial applications and Web-based HMI solutions with intuitive widgets for UI design, seamless integration and mobile-friendly solutions.

A-Sphere HMI Platform
Alphagate
Germany ⊖

The A-Sphere HMI platform (from 2025 known as RANA) offers a customizable solution for the machinery industry. A-Sphere offers easy human-machine interface creation without programming skills. It is PLC-independent and seamlessly integrates various systems. Compatible with AI and Augmented Reality (AR), allows companies to easily integrate innovations like AI-driven maintenance or AR-supported training.

AVEVA InTouch HMI
Aveva
Great Britain ⊖

AVEVA InTouch HMI is powerful visualization software that helps operators optimize interactions with industrial automation systems. The Unlimited edition offers unlimited licensing, regulatory compliance, shift reporting, and advanced process analysis with an accurate historian, enhancing performance across industrial and manufacturing processes.

Infont
Mirmit
Spain ⊖

Infont is industrial management software for the furniture sector. It enables real-time monitoring of productivity across all types of workstations—both manual and automated—covering processes from transformation to manipulation. It supervises productivity in real-time, identifies bottlenecks, optimizes workflows, and improves efficiency. It offers complete traceability of orders, operator activities, and inventory movements, with flexible customization and easy integration via APIs.

Panel cutting machine guidance system for the operator
Homag Group AG
Germany ⊖

IntelliGuide is a modular operator assistance system for panel dividing saws, featuring interactive software, LED signals, cameras, and laser projections to guide operators step by step, prevent errors, and optimize workflow. It enhances ergonomics, safety, and efficiency, adapting intelligently to operator actions and supporting intuitive human-machine interaction.

Examples

Bona
Sweden

Bona AB provide products for the installation, maintenance and renovation of wooden floors. Bona settled for a Beijer Electronics automation solution with HMI operator panels for controlling machinery used in their manufacturing process. The remotely controlled system was chosen for its speed, benefits of simple configuration and the reliability associated with powerful diagnostic features.

Glaston
Finland

Glaston is a leading provider of glass processing technologies and services for several industries, as furniture. A user-oriented HMI solution was developed, with seamless integration of machines for higher efficiency, user-friendly UX/UI design for easy operation and quick onboarding and development of apps with features such as process analysis and maintenance assistance to ease operations.

Fecken-Kirfel
Germany

Development of a trend-setting, graphically high-quality web HMI. The development of the HMI had to stay at the company. Smart-HMI's WebIQ Designer allows the creation of 100% web-based dynamic user-interfaces low-code, simply using drag-and-drop. The tool was used for the in-house development, while Smart HMI only provided selective support.

Nowy Styl
Poland

Nowy Styl factory produces thousands of unique furniture components per shift, requiring advanced HMI solutions like Homag's powerTouch and a robust MES such as Homag's Wood Factory. Operators use HMIs to monitor production, manage part data, oversee automation, and quickly adapt to changes, ensuring efficient, customized manufacturing.

Cadorin
Italy

Cadorin has implemented the SCM "celaschi tmc" machining line, fully compliant with Industry 4.0 standards. This solution includes an HMI system that simplifies operator interaction and provides real-time control over production data. It allows for highly flexible processing, tailored to Cadorin's artisanal yet advanced manufacturing needs. The integration enhances traceability, efficiency, and precision. This collaboration reflects a shared commitment to sustainable and high-quality craftsmanship.

Ardis Perform + Silva
Belgium

The ARDIS blog post on Silva highlights how implementing PERFORM transformed production management. Each workstation now features an interactive screen with real-time, up-to-date task lists, ensuring clear communication—even for non-native speakers. The human interface allows managers to assign, reprint interactively on demand, and reprioritize tasks remotely, reducing chaos and improving coordination across the shop floor.

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Implementation difficulty: **Medium**
Economic viability: **Medium**

AIoT for smart manufacturing

Description

AIoT, or Artificial Intelligence of Things, is the integration of Artificial Intelligence (AI) technologies with the Internet of Things (IoT) infrastructure. This combination enhances the capabilities of IoT devices by enabling them to analyze data at the Edge, make decisions, and learn from experience without human intervention. Edge computing is a distributed computing paradigm that brings computational capabilities closer to the source of data, like IoT devices or users, to reduce latency and improve performance. AIoT along with Edge Computing, aim to create more efficient IoT operations, improve human-machine interactions, and enhance data management and analytics.

[1] IoT & AI based data business value chart

The key components of the AIoT are as follows:

- **IoT Devices:** The sensors, actuators, and other devices that collect, process and transmit data.
- **Connectivity**: This encompasses networks and protocols that enable IoT devices to communicate with each other and central systems.
- **Data Processing**: AI algorithms process the data collected by IoT devices to extract meaningful insights.
- **Cloud Computing:** Provides the necessary infrastructure for storing and processing large volumes of data.
- **Edge Computing:** Facilitates data processing in proximity to the source of data generation, thereby reducing latency and bandwidth utilization.

[2] *Example of a IoT network (Source: HMS Networks)*

AIoT has already given rise to numerous industrial applications. One example is the autonomous control of production facilities. Other areas are logistical optimization or predictive maintenance management.

Despite its promising potential, one major challenge is interoperability. Many companies use IIoT (Industrial Internet of Things) devices and platforms from different manufacturers, which are not always seamlessly compatible. This complicates the implementation of integrated AIoT solutions and necessitates standardised interfaces and protocols. A well-chosen AIoT platform facilitates the integration of new devices, enables easy scaling, and supports the flexible adaptation of an IIoT strategy. It also allows integration with other systems and technologies, such as ERP or CRM systems, thereby embedding IIoT technologies into existing business processes.

Another critical aspect is data preparation. In IoT environments, data quality is often poorer than businesses assume. Applying AI to inadequately prepared data produces subpar models that fail to deliver expected results. Therefore, it is crucial to prepare and enrich data appropriately for analysis using a reliable IoT platform.

At the same time, exciting trends are emerging that will shape the AIoT ecosystem in the coming years. One such trend is the use of generative AI, which not only analyses data but also generates new designs or optimisation proposals. Another trend is the integration of 5G technologies, which enable ultra-fast and reliable

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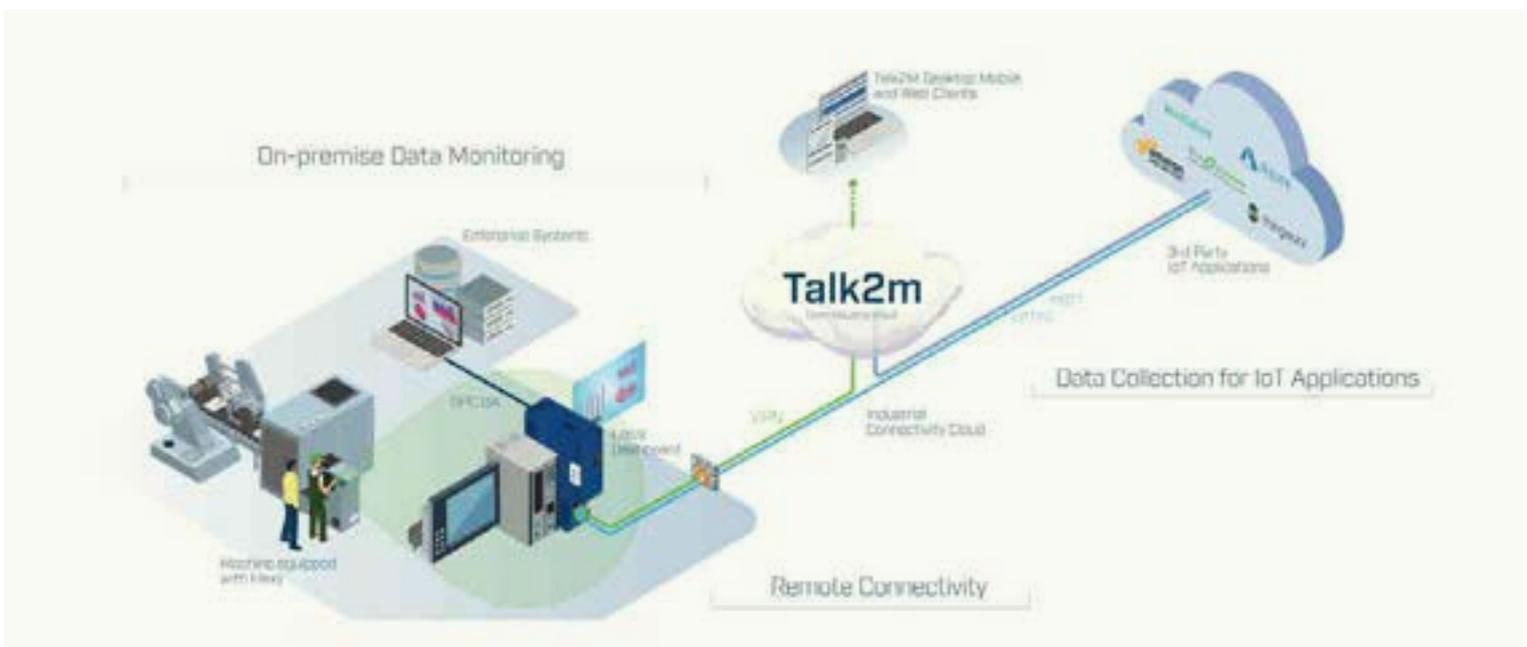
connectivity. This is particularly important for applications requiring high bandwidth or low latency, such as autonomous vehicles or real-time controls.

Despite its potential, integrating AI into manufacturing poses challenges, including significant initial investment, the need for skilled workers to develop and maintain AI systems, and concerns over data privacy and security. Additionally, there is the challenge of integrating AI technologies with existing Information Technologies (IT) and operational technologies (OT) infrastructures. IT refers to the use of computer systems to process, store, and exchange information, while OT includes the systems that monitor and control physical devices, processes, and infrastructure in industrial settings.

As AIoT technology continues to evolve, its applications in manufacturing are expected to expand further, potentially leading to fully autonomous factories and highly personalized production at scale. The ongoing development of AIoT will also likely see an increased emphasis on collaboration between humans and machines, leveraging the strengths of both to achieve optimal outcomes.

3 *Mini industrial PCs (Source: Beckhoff)*

Application

AIoT (Artificial Intelligence of Things) in manufacturing empowers advanced capabilities for data acquisition and intelligent processing. By combining IoT connectivity with AI-driven analytics, it enables real-time, d ta-informed decision-making that transforms industrial operations.

4 *Significance of AI in manufacturing (Source: Orange mantra)*

Predictive Maintenance: AIoT can predict equipment failures before they occur by analyzing data from sensors embedded in the machinery. This approach offers the benefit of reducing downtime and maintenance costs while extending the lifespan of equipment.

5 *Data monitoring for predictive maintenance (Source: Adobe Stock)*

Supply Chain Optimization: AIoT can track goods in real-time, predict demand, and optimize inventory levels. Through these capabilities, it enhances supply chain visibility, reduces costs and improves delivery times.

Energy Management: AI helps in optimizing energy use in manufacturing facilities by analyzing data from various sources to identify inefficiencies and suggest improvements. For example, AI can optimize the operation of HVAC systems based on the number of people in a building, the weather, and the specific needs of the manufacturing process, significantly reducing energy costs. AIoT systems can monitor and control energy usage in industrial facilities to reduce energy consumption, lower costs, and support sustainability initiatives.

6 Energy Management Software Dashboard (Source: Etalytics)

Quality Control: AIoT can automate the inspection of products using computer vision and machine-learning algorithms. This automation improves product quality and reduces the need for manual inspection labor.

Safety and Security: AIoT can enhance workplace safety by monitoring environmental conditions and detecting hazardous situations. This implementation reduces the risk of accidents and ensures compliance with safety regulations.

Smart design and manufacturing: AI facilitates the design process through generative design software, which can generate a wide range of design alternatives based on specified criteria, such as materials, manufacturing methods, and performance requirements. This not only speeds up the design process but also enables more customization, allowing manufacturers to more

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easily meet specific customer requirements. Also, AIoT enables real-time monitoring and optimization of manufacturing processes. This implementation increases efficiency, reduces waste, and improves product quality.

Implementation Aspects

■ Implementation difficulty: Medium

Ensuring data accuracy, security, and privacy is crucial to the success of AIoT initiatives. One of the most significant challenges facing AIoT adoption is ensuring data privacy and security. The vast amounts of data generated by IoT devices include sensitive information such as financial transactions, and operational data from critical infrastructure. Moreover, unlocking the full potential of AIoT requires a shift in organizational culture. Decision-makers need to embrace data-driven strategies and cultivate an environment of innovation and continuous improvement. It's also vital to invest in training and upskilling employees so they can effectively utilize AIoT technologies for successful implementation.

To make AIoT adoption smoother and less daunting, a practical approach is start small and scale up gradually. Simulation provides a low-risk, manageable entry point that can eventually lead to the seamless integration of digital twins into manufacturing operations.

■ Economic viability: Medium

Implementing large scale AIoT technology often requires significant investment in sensors, IoT devices, software, infrastructure and skilled personnel. However, some of the technological solutions described represent a very low cost of implementation for SME´s.

■ Human factors

Adopting AIoT technology often requires significant organizational changes and a shift to a data- driven and innovation-oriented workplace culture. Resistance to change, a lack of awareness, or hesitation to adopt new technologies can hinder adoption. However, it's clear that employees need to close the digital skills gap, recognize the practical benefits of AIoT in their roles, and upskill without disrupting workflow continuity or employee well-being.

AIoT can improve efficiency, decision-making, customer experience and transform how humans interact with their environment. For example, AIoT can automate repetitive tasks like data entry and scheduling, freeing up employees to focus on more strategic work. It can also analyze large amounts of data to help businesses make informed decisions and detect patterns and provide accurate predictions.

Manufacturers can reinforce the value of AIoT to stakeholders by highlighting benefits like improved product quality, lower energy costs, enhanced operational efficiency, and safer working conditions.Key factors for successful AIoT adoption include strong executive support, investment in change management and digital infrastructure, and the adaptability of the workforce.

Transparent communication and participatory design processes are also essential to increase acceptance and trust in AIoT systems. Workers should be actively involved in the co-design of smart tools that affect their daily tasks, and ethical considerations—especially related to data privacy and algorithmic decision-making—must be addressed from the outset.

In conclusion, AIoT will not replace human workers, but those who master AIoT tools may outperform those who don't. As automation takes over repetitive tasks, human workers will increasingly focus on guiding, fine-tuning, and optimizing these smart systems. The human brain is
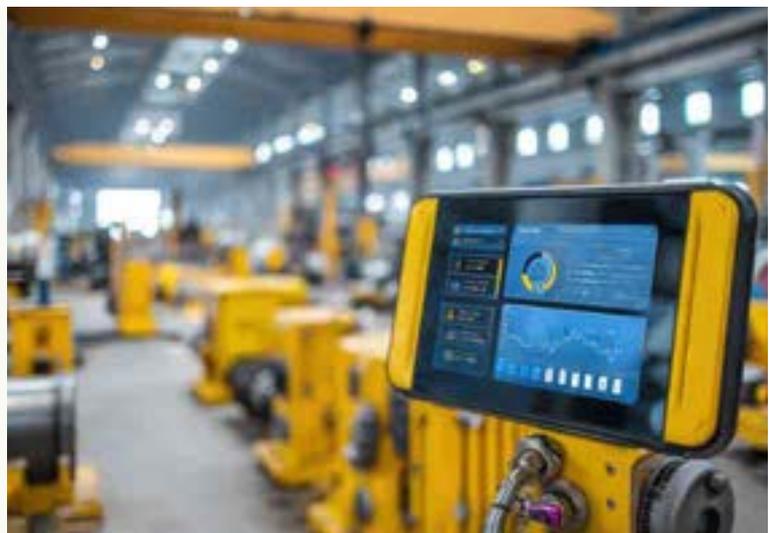
still one of the most advanced and efficient systems for processing information. Although AI can analyze massive datasets and detect patterns at incredible speeds, it doesn't possess the subtle, intuitive understanding that humans do. We excel at grasping context, reading between the lines, and making insightful connections from limited information—capabilities that remain beyond the reach of even the most powerful AI systems.

■ Environmental factors

The integration of AIoT in furniture manufacturing helps reduce the carbon footprint by reducing energy, water and resource use, minimizing waste, improving logistics and enhancing overall efficiency. It also helps to reduce repetitive tasks from staff and let them focus on more valuable activities. Additionally, AIoT enables predictive maintenance, which extends the lifespan of equipment and reduces unnecessary interventions. These applications can significantly lower the environmental impact, ensuring that manufacturing processes align with environmental standards and regulations.

However, AIoT also introduces significant environmental impacts due to its dependence on embedded electronics, high data volumes, machine learning models, and persistent connectivity.

At the device level, AIoT systems involve billions of interconnected sensors, microcontrollers, actuators, and edge processors. These components are often small, but their sheer volume creates a substantial environmental burden. They typically contain rare earth elements, heavy metals, and engineered plastics, whose extraction and refinement are linked to high environmental impacts. Many AIoT devices are also energy-constrained and designed for limited lifespans, increasing their contribution to e-waste.The manufacturing footprint is further compounded by the integration of AI-capable hardware. These chips involve complex, high-energy fabrication processes and frequent technological obsolescence cycles.

On the data side, AIoT systems generate and process massive volumes of data. While edge computing reduces latency and bandwidth requirements, many AIoT architectures still rely on cloud computing for data aggregation, long-term storage, and complex model training. As a result, AIoT contributes to the growing energy and water footprint of data centers during use.

The AI models used in AIoT applications—particularly deep learning algorithms for vision, natural language processing, or anomaly detection—can be highly energy-intensive to train.

■ Alignment with certifications and regulations

Implementing a AIoT in a factory involves compliance with several regulations and standards related to data security, interoperability, environmental impact, and industry-specific requirements. Below are some key regulatory considerations:

Cyber Resilience Act (CRA): The CRA introduces mandatory cybersecurity requirements for products with digital elements, encompassing both hardware and software, including AIoT devices.

· Mandatory Security Measures: Manufacturers must implement security features throughout the product lifecycle, from design to decommissioning.

· Vulnerability Reporting: Companies are required to report exploited vulnerabilities to authorities within 24 hours and provide comprehensive updates within 72 hours.

· Security Updates: Devices must receive security updates for a minimum of five years, unless the expected product lifespan is shorter.

· Penalties for Non-Compliance: Non-compliant products can be banned from the EU market, with fines up to €15 million or 2.5% of global turnover.

IIC (Industrial Internet Consortium): Security Framework – Defines security best practices for industrial IoT and digital twins.

AI Act (EU) – Regulates AI-powered decision-making in industrial settings

EU Green Deal & Carbon Border Adjustment Mechanism – Requires digital monitoring of carbon footprints in industrial operations.

AIoT for smart manufacturing
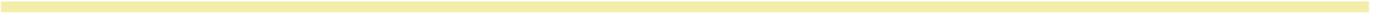
Solutions

Embedded AI based predictive maintenance for industrial electric motors
Advantech
Taiwan ⊝

Electric motor predictive maintenance prevents costly failures using vibration and temperature monitoring. Devices like the WISE-2410, with ARM Cortex-M4, LoRa, and edge computing, analyze data onboard to extend battery life up to 2 years. With IP66 protection, it suits motors, pumps, HVAC systems, and more for efficient, wireless condition monitoring.

Industrial (easy) IoT connectivity devices for PLCs and machinery
HMS Networks
Sweden ⊝

HMS industrial communication products connect millions of PLCs, robots, and devices to software and remote systems. Their EWON device family enables secure, easy remote PLC access without firewalls or port forwarding, even in China. Supporting multiple PLC brands, EWON bridges industrial data to remote users via Wi-Fi or cellular networks.

Fanless ultra-compact Industrial PCs and OpenVINO
Open Vino (Intel Corporation)
United States ⊝ ⊝

Scalable ultra-compact Industrial PCs combine maximum computing power in what is currently the most compact format with a wide range of options for installation in the control cabinet. It is ideally suited for control, visualization and communication, for example into the cloud. They offer computing power for a wide range of automation and visualization tasks. Due to their impressive computing power in relation to their size, the PCs are mainly suited for use in Industrie 4.0 applications, for example as an IoT gateway.

Industrial PCs are used to run advanced AI frameworks and software such as OpenVINO. This is an open-source software toolkit for optimizing and deploying deep learning models. It enables programmers to develop scalable and efficient AI solutions with relatively few lines of code

DeviceWISE® AI
Telit Cinterion
United States ⊝

Incorporating AI into IoT, the platform supports Visual Inspection with advanced algorithms and deep-learning techniques, Data-Driven Optimization for uniform product quality, with data collection and analysis for predictive maintenance. Supporting no-code or low-code systems the platform enables process optimisation (also improving energy consumption can save costs).

Asus Ebs-4U – Smart Replenishment
ASUS
Taiwan ⊝

ASUS IoT and Macnica DHW's Smart Replenishment solution uses AI and image recognition to automate restocking of non-barcoded perishables. Running 24/7, it provides real-time stock visibility, eliminates manual checks, and enhances efficiency. The end-to-end platform combines ASUS IoT hardware and analytics with Macnica's UI for easy, scalable store deployment.

All-in-One Edge Computing Gateway AIoT-5G-G06
Trugemtech
China ⊝

The TruGem AIoT-5G-G06 is a 1U rackmount all-in-one AIoT (Artificial Intelligence of Things) 5G Edge Computing Gateway, designed for straightforward integration into standard computer room cabinets. This unit integrates AIoT functionality with high-performance data processing capabilities, making it suitable for industrial and enterprise-grade IoT computing scenarios. It supports real-time data analytics and automated decision-making at the edge, reducing latency and minimizing the need for cloud round-trips. The TruGem AIoT-5G-G06 is intended for use in environments that require continuous data processing, monitoring, and response capabilities close to the data source.

Examples

Interior Works
Poland

Asset performance management: Users can enhance performance by being continually updated on how the assets are meeting KPIs. Further, user get to see if those existing KPIs still make sense. With performance management apps built directly on the AIoT platform, users receive automated alerts whenever a deviation takes place and can swiftly respond to anomalous behavior. The real-time data and feedback from machines allow them to refine KPIs to get the most out of machine performance. This translates into more effective use of assets and faster production times.

Pressac Communications Ltd
United Kingdom

Energy consumption tracking and management: Sustainability is quickly becoming a business priority for manufacturers because of consumer demand and stricter regulations. Due to this, we can expect to see a strategic switch towards cleaner and greener operations, such as the use of renewable energy, recyclable materials, reductions in emissions, excessive packaging, and water use. Energy consumption is minimized by using the most energy-efficient options for connected assets. Energy consumption tracking and management with AIoT across manufacturing plants can help to identify patterns and reduce anomalous energy leaks, track energy peaks, investigate ways to cut energy waste, and better comprehend the way each industrial asset contributes to overall energy consumption.

CPCON Group
United States

Inventory and supply chain management: An integrated AIoT platform enhances inventory management and resource forecasting across manufacturing sites. By leveraging real-time analytics, it improves supply chain transparency, automates decisions, and boosts resilience. AI-powered tools help anticipate disruptions, manage complex inventories, and improve efficiency, ultimately leading to better supplier quality control, customer experience, and business performance.

Prohan
Poland

Computer Vision System for defects early detection: Early detection of flaws on the production line is key for wood furniture manufacturer using hardwoods. With a solution based on computer vision and machine learning algorithms, gaps, cracks, and splits in panels can be identified immediately after the gluing step, at a stage where machine speed makes defects undetectable by the human eye

Axiomtek
Taiwan (Head Office)

Axiomtek's AI-integrated service robots combine AI, cloud, big data, and biometrics for sensing, decision-making, and autonomous control. Powered by high-performance edge computers like the eBOX, IPC, AIE systems, and system-on-modules, they offer flexible I/O, compact design, and customization. Axiomtek also provides tailored design services to enhance productivity, reduce costs, and speed deployment.

Fanuc
Japan

AI-enabled collaborative robots in woodworking automate tasks like sanding, routing, and handling, improving precision, quality, and safety by minimizing human exposure to dust and hazards. With AIoT integration, robots inspect quality in real time, learn from outcomes, and optimize processes, boosting productivity and enabling smarter, adaptive, and more efficient manufacturing operations.

11

Transforming Homes into Smart Ecosystems

The Internet of Things (IOT) connects various devices within your home, allowing them to communicate with each other and the internet, enhancing automation and responsiveness

Components of an IoT System

Sensors

Detect changes in the environment, such as temperature or motion.

Ex: Security Systems

Actuators

Performs actions based on commands, like adjusting the thermostat or locking a door.

Ex: Smart Lighting & Thermostats

Connectivity

Devices connect and communicate through Wi-Fi, Bluetooth, or other protocols, sending and receiving data.

Data Processing

Data collected by sensors is analysed either locally or in the cloud to make informed decisions.

User Interface

Homeowners interact with IoT devices via apps, voice commands, or automation, providing control and receiving feedback.

Implementation difficulty: **Low**
Economic viability: **High**

The journey of IoT and connectivity

Description

IoT, or the Internet of Things, is a network of physical objects—"things"—embedded with sensors, software, and other technologies that allow them to connect and exchange data with other devices and systems over the internet. Essentially, it's about connecting everyday objects to the internet, enabling them to collect, share, and act upon data. But IoT is not only about hardware and connectivity. IoT enables many new commodity services and is transforming homes into smart ecosystems and shaping the way companies focus their business.

1 *IoT is transforming homes into smart ecosystems (Source: Codiant)*

Here's a breakdown of the elements that are key for IoT:

- **Connected objects:** IoT encompasses a wide range of home devices or connected objects, from appliances like thermostats, lighting systems, and voice assistants to wearables, and smart home security systems. These devices form the physical layer of the IoT ecosystem, interacting with users and the environment.
- **Sensors:** These devices are equipped with embedded sensors that collect data from their surroundings(such as temperature, humidity, motion, light, CO_2 levels, or occupancy). This raw data forms the foundation of context-aware applications that enable intelligent automation and control.
- **Gateways and communication:** Data collected by sensors is transmitted via communication protocols such as Wi-Fi, Zigbee, Bluetooth, LoRaWAN, or NB-IoT. Gateways act as intermediaries that aggregate and preprocess this data before sending it to the cloud or local servers
- **Data processing and analytics:** Once transmitted, the data is processed in the cloud or at the edge. AI and machine learning algorithms analyze the information to detect patterns, predict user behavior, and enable automation.
- **Control systems and interfaces:** Users interact with the IoT ecosystem through dashboards providing real-time control, monitoring, and configuration of devices.
- **Services and applications:** Ultimately, IoT enables a wide range of services such as predictive maintenance, energy optimization, health monitoring, and enhanced comfort and security.

As Internet of Things (IoT) technology becomes more closely integrated into everyday systems, lifestyles, and businesses, it is generating a greater need for cyber security. Cybersecurity technology for Internet of Things (IoT) devices is critical because of the increasing number of connected devices and sensitive data they handle. IoT devices, ranging from smart home appliances to industrial sensors, are often vulnerable to cyber threats owing to limited processing power, lack of built-in security features, and the complexity of IoT ecosystems. Below are the key cybersecurity technologies and practices designed to protect IoT devices.

2 *IoT device types (Source: Istock)*

Starting in August 2025, new European regulations will require all IoT equipment (including devices using Wi-Fi or Bluetooth) to comply with strict cybersecurity standards. Manufacturers must ensure device security throughout the product's life cycle, including clear vulnerability disclosure, defined support periods, and the use of unique or user-defined passwords to prevent default credential risks. Security features such as Secure Boot, firmware validation, PKI-based authentication, and optional Multi-Factor Authentication (MFA) will help protect against unauthorized access.

3 *IoT devices at home (Source: AdobeStock)*

Protecting both data and network connections is a key part of making smart devices safe to use. This means making sure that information sent between devices stays private and can't be read or changed by others. These protections are especially important for IoT devices often found in smart homes, where security tools like protected connections and software updates help keep systems up to date and secure.

4 *Smarthub Home IoT ecosystem (Source: AEOTEC)*
5 *IoT Dashboard (Source: AdobeStock)*

Application

IoT is transforming our environment by enabling new ways of managing assets, improving efficiency, and providing better insights through data analysis. IoT applications include but are not limited to:

- **Smart homes:** voice assistants, automated vacuum cleaners, thermostats and actuators.
- **Environmental monitoring:** temperature and humidity, IAQ (CO2, VOCs…)
- **Security:** smart cameras, motion sensors, and locks, provide real-time monitoring and alerts, enhancing home safety.
- **Metering devices:** smart meters for electricity, water and gas included and could be placed in addition to the ones managed by supplier companies.
- **Smart Appliances:** IoT-enabled appliances, like smart

refrigerators, smart ovens, and smart dishwashers, can be controlled remotely and offer features like recipe suggestions and automated ordering.

- **Wearables:** fitness trackers, smartwatches and other health and wellness related gadgets.
- **Smart building:** occupancy and people flow monitoring, access control and energy saving among other applications.
- **Connected cars:** parking occupancy, remote control and self-service appointments are some of the applications.
- **Location and tracking:** of both people and goods.

6 *Thermal controler and mobile control dashboard (Source: EVEHOME)*

Beyond individual device functions, IoT systems enable continuous data monitoring, collection, and processing in real time, allowing for predictive insights and adaptive behavior. These devices often interact with cloud-based platforms or edge computing units that analyze sensor data and make autonomous decisions or trigger alerts. Control systems and mobile apps offer users centralized access to configure, manage, and visualize IoT operations remotely. This bidirectional communication between connected devices and control infrastructures facilitates more responsive environments and supports automation, energy efficiency, and security.

Implementation Aspects

■ Implementation difficulty: Low

Consumer grade IoT electronics need to be easy to install and operate both for the integrator and the end user. Sometimes producers embrace convenience or prioritize security. However, it should not be necessary to choose one or the other. Ensuring data accuracy, security, and privacy is essential for the success of networked sensor initiatives. Robust cybersecurity measures are vital to safeguard sensitive information and prevent unauthorized access. Regulatory requirements will enforce producers to bring cybersecurity into focus and they will be surely able to keep implementation difficulty low.

■ Economic viability: High

Implementing Networked Sensors technology at large scale often requires significant investment in sensors, IoT devices, software, infrastructure and skilled personnel. However, for small and medium scale deployments, IoT is an already mature technology with a proven return of investment.

■ Human factors

IoT adoption is accelerating in consumer environments, particularly through smartphone-connected or voice-controlled devices. These technologies are becoming ubiquitous in everyday life—from smart thermostats and lighting to security systems and air-quality sensors.

For manufacturers, integrating networked sensors into furniture or home interiors represents a paradigm shift: it transforms one-off sales into continuous service models, with revenue from data-based services like predictive maintenance, remote monitoring, or user analytics.

Implementing IoT systems at scale requires a significant cultural and organizational transformation. Companies must evolve toward a data-driven mindset and foster cross-functional collaboration between IT, product design, and customer service.

To ensure adoption and usability, HR must invest in upskilling employees in areas such as data literacy, user interface interaction, and cybersecurity protocols. Operators and support staff should also be trained to interpret sensor data and respond appropriately.

Furthermore, participatory design approaches—where employees are involved in the testing and improvement of smart systems—enhance ownership and acceptance. Ethical aspects such as data privacy, employee monitoring boundaries, and algorithmic transparency should be addressed proactively in dialogue with staff.

In short, human acceptance, trust, and digital fluency are critical to successful IoT deployment.

■ Environmental factors

The implementation of networked sensors plays a key role in reducing the carbon footprint minimizing waste and increasing energy efficiency. IoT devices can significantly reduce home energy consumption by enabling real-time monitoring, automation, and optimized energy

management. In addition, networked sensors serve as a foundation for predictive maintenance, extending the lifespan of equipment such as boilers or air conditioners and minimizing unnecessary interventions.

However, its environmental footprint is growing rapidly due to the proliferation of embedded electronics, continuous data exchange, and infrastructure needs.

At the hardware level, IoT devices include sensors, microcontrollers, communication modules (e.g., Wi-Fi, Bluetooth, LTE), and batteries. These components are typically composed of rare earth elements, copper, lithium, cobalt, and engineered polymers, all of which carry significant environmental impact. The miniaturization and integration of electronics, while improving functionality, often hinder disassembly and recyclability, leading to concerns over electronic waste (e-waste).

The manufacturing phase of IoT devices is energy-intensive, involving semiconductor fabrication, circuit board production, and assembly in controlled environments. Many devices are designed to be inexpensive and disposable, with short product lifespans (2–5 years), further intensifying their environmental impact. Moreover, the global scale of IoT means even small impacts per device translate into substantial aggregate effects.

During the operation phase, most IoT devices individually consume minimal energy. However, their cumulative electricity demand is significant, especially when scaled across millions of nodes. In addition to the power needed to run devices, data transmission, cloud storage, and analytics require a substantial digital infrastructure.

Many IoT systems are cloud-dependent, transmitting sensor data to centralized servers for processing. This increases the environmental footprint, particularly when low-value or redundant data is continuously streamed.

■ Alignment with certifications and regulations

Implementing Networked Sensors in a factory involves compliance with several regulations and standards related to data security, interoperability, environmental impact, and specific requirements. Below are some key regulatory considerations:

- The essential requirement set out in Article3(3), point (d), of **Directive 2014/53/EU** shall apply to any radio equipment that can communicate itself over the internet, whether it communicates directly or via any other equipment ("internet-connected radio equipment").
- **prEN18031-1**: Internet Connected Radio (security& network risk)
- **prEN18031-2**: Various Radio equipment (Toys, wearable) (security& privacy risk)
- **prEN18031-3**: Radio managing currency (security& financial risk)
- **GDPR (General Data Protection Regulation - EU)**: Governs data collection, processing, and storage, ensuring privacy of personal and industrial data.
- **ISO/IEC 27001**: International standard for information security management.

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The journey of IoT and connectivity

Solutions

Fiware Middleware Platform
Nivid Technologies
United States ⊝

FIWARE is an open-source platform that supports the development of smart applications using open standards and advanced technologies. It enhances interoperability, fosters innovation, reduces costs, and improves public services. Proprietary solutions, like Telefónica's smart city platform, build on FIWARE's core—leveraging its APIs, shared data models, and real-time data exchange for seamless compatibility.

Alignment of manufacturer´s products with Smart Home IoT Ecosystem
Open Home Foundation
New Zealand ⊝ ⊝ ⊝ ⊝

Home Assistant ⊝, Google Home ⊝, Apple HomeKit ⊝, Tuya Home ⊝, Samsung SmartThings ⊝… These companies are not just creating products; they are developing IoT ecosystem brands that provide convenience, security, and efficiency. The interconnection among things means that users are no longer satisfied with accessing a single product/service but start to demand a scenario-based holistic solution.

New IP based low power connectivity protocols for smart home
Thread Group
United States ⊝

Wi-Fi was once inefficient for battery-powered IoT devices, but Wi-Fi 6 introduced features like Target Wake Time (TWT) to reduce power use. This enabled new IoT protocols without extra hardware. Thread, a low-power mesh protocol, offers secure, scalable communication. Matter, launched by major tech firms, builds on Thread and Wi-Fi to ensure seamless smart home device interoperability. ▶

IoT solution for safety in living and working environments
Netmamo
France ⊝

The Netatmo Smart Smoke Alarm is a standalone, Wi-Fi-enabled smoke detector that offers real-time alerts to your smartphone. It features a high-performance photoelectric sensor, emitting an 85 dB alarm when smoke is detected. With a 10-year battery life, it eliminates the need for frequent battery replacements. The device also includes a self-test function, monitoring its battery, sensor, and Wi-Fi connection, and notifying you of any issues. Installation is straightforward, and it integrates seamlessly with the Home + Security app, compatible with both iOS and Android devices.

Fast-track development framework
Blynk Technologies Inc.
United States ⊝

Blynk is a low-code IoT platform that accelerates product development with drag-and-drop app builders, device management, and cloud infrastructure. It supports rapid prototyping, cross-platform hardware, and seamless integration, enabling fast, scalable IoT solutions with minimal coding.

IoT sensors and devices
TEKTELIC Communications
Canada ⊝

TEKTELIC designs and manufactures LoRaWAN® enabled IoT devices that convert environmental and operational data into actionable insights. Their sensors can monitor a range of parameters, including temperature, motion, air quality, and equipment status, across both indoor and outdoor environments.

These devices are used in applications such as asset tracking, environmental monitoring, and building performance optimization.

Examples

Ojmar
Spain

Smart IoT locking systems: OJMAR, a company with over 90 years in furniture lock manufacturing, has evolved from producing durable mechanical locks to offering IoT-enabled electronic solutions. Initially focused on one-time sales, it now generates revenue through maintenance, software, and data analytics. Serving 24-hour sports centers, OJMAR leverages IoT for predictive maintenance and user data, embracing servitization and digital transformation.

Ikea
Sweden

IoT built in furniture (product & service): The IKEA STARKVIND table has a built-in air filter that removes dust particles, allergens and pollutants from the surrounding air, contributing to a cleaner and healthier environment in the room where the table is located. It features a particle filter that has been optimized to filter approximately 99.5% of airborne particles.

Ori Living
United States

Expandable apartments with robotic furniture: Founded by Hasier Larrea, Ori Living makes space transformation effortless with its plug-and-play toolkit that empowers architects and developers to design more innovative, flexible, and desirable living environments. Ori, introduces a dynamic development model that better aligns the needs of both renters and developers—paving the way for adaptable, and intuitive living. Backed by a decade of innovation, thousands of real-world installations, and roots in MIT reearch, Ori's proprietary robotic systems offer a proven design solution. They give architects the tools to create transformative in-home experiences and space-expanding apartment typologies that integrate seamlessly with any construction type.

Morfeus (in collaboration with Cosmob)
Italy

Smart solutions for the quality of sleep: The Italian brand Morfeus, in collaboration with Cosmob, the Technological Centre for the Wood and Furniture sector, has developed an innovative mattress integrated with advanced sensors to monitor key parameters that influence sleep quality. Specifically, sensors embedded within the mattress track temperature, humidity, and sleep phases, while external sensors connected to the system measure environmental factors in the bedroom, such as temperature, humidity, air quality, brightness, and noise. All collected data is analyzed and communicated to the user through a dedicated smartphone app, which provides personalized advice and suggestions to help improve sleep quality.

Autonomous
United States

Autonomous desk powered by AI: Autonomous Desk enables automated height adjustment to promote healthier working habits. During an initial calibration period, the user manually sets preferred sitting and standing heights. The desk records this data to establish personalized movement patterns.

Once configured, the desk transitions between sitting and standing positions based on learned user behavior, aiming to reduce sedentary time throughout the workday. Upon detecting the user's presence in the morning, it automatically adjusts to the preset standing height. If prolonged sitting is detected, the system issues a prompt encouraging the user to stand. Regular posture variation can contribute to improved ergonomics and long-term health outcomes.

Eight Sleep
United States

Smart mattress with AI sensored and health tracking technologies: EightSleep Pod leverages IoT and AI-powered sensors to deliver real-time health tracking, predictive illness alerts, and adaptive temperature and elevation controls, setting itself apart with immersive sleep optimization, smartphone-linked monitoring, and automated adjustments for personalized rest, not possible with traditional products.

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Implementation difficulty: **Medium**
Economic viability: **Medium-High**

Generative AI for custom design and fast prototyping

Description

Foundation models for image generation represent an advanced category within the field of generative artificial intelligence. They are the result of the evolution of deep neural networks (Deep Learning) and machine learning techniques focused on visual generation. This technology enables users to optimise and accelerate creative processes, delivering high-quality results. In the furniture sector, it has the potential to become an intelligent creative assistant for designers, interior architects and other roles involved in the creation and personalisation of products. [1]

The origins of AI-based image generation lie in key advances over the past decade. It began in 2014 with the introduction of Generative Adversarial Networks (GANs) by Ian Goodfellow, followed by models such as Style-GAN, BigGAN and diffusion models, capable of generating realistic faces, images and videos from inputs such as text, sketches, audio or structured data.

A turning point arrived in 2021 with DALL·E 1, the first multimodal generative model from OpenAI to achieve viable results in transforming text into image. This marked the consolidation of a technology that for years had produced limited outcomes, significantly expanding the possibilities of design, communication and spatial ideation.

In 2022, the technology became more widely accessible with the release of DALL·E 2, offering improved output quality, alongside other models such as Imagen (Google), Stable Diffusion (open source) and Midjourney. Throughout 2022 and 2023, new techniques emerged, such as LoRA (Low-Rank Adaptation), which enables efficient training, and tools like ControlNet, img2img and inpainting/outpainting, which allow for greater control over composition, detail and canvas expansion. Platforms like ComfyUI also offer visual environments for working with complex workflows on models such as Stable Diffusion or Flux. [2]

The key driver behind the boom of these tools is not solely the technology itself. Thanks to affordable, moderately complex tools, users now have access to capabilities that were previously limited to research contexts. In addition to broadening the offering, new tools and techniques are giving rise to a community of users who experiment with, adapt and personalise models for specific use cases.

There are already multiple commercial solutions based on these models, ranging from visual platforms exploring new business models through this technology—such as Freepik or Krea AI—to integrations into industry-standard tools like Autodesk Revit (with Veras) or SketchUp (with SketchUp Diffusion). This enables companies to harness the potential of generative AI without disrupting their workflows, facilitating adoption and reducing the learning curve. [3]

Generative image AI offers the furniture industry a new way to explore and visualise concepts in the early stages of the creative process. From moodboard and prototype generation to material simulation, it enables rapid iteration across multiple alternatives, reducing time and operational costs.

Furthermore, multimodal generative models drive what is known as Augmented Creativity: a fluid collaboration between designer and artificial intelligence. While the AI suggests visual variants, unexpected ideas or specific adjustments, the professional remains focused on strategic decision-making.

The following sections will delve deeper into the applications and impact of this technology on the furniture sector, where it is positioned as a high value-added tool that enhances operational efficiency, fosters creative innovation, and supports strategic decision-making throughout the design and product prototyping process.

Application

In the furniture sector, generative AI helps streamline key tasks in the design and product prototyping process, such as generating visual variants, reviewing prototypes, or creating visual documentation. This enhances operational efficiency and supports both creative and technical decision-making [4]

Automated Moodboards for Design Concepts

These tools enable design and product teams in furniture companies to automatically generate moodboards from textual descriptions or visual references. They facilitate the synthesis of aesthetic trends, colour palettes and material combinations (such as wood, textiles, metals or finishes) into coherent visual compositions, allowing teams to explore emerging market trends in real time. They also contribute to the early identification of technical constraints or customer preferences, improving coordination between design, production and sales. This not only optimises profitability in terms of cost and time but also accelerates creative decision-making, leading to outcomes that are more closely aligned with client expectations. [5]

Generative AI for custom design and fast prototyping

Visual Proposals During Product Prototyping

From the initial generation of digital sketches to final visualisations, these tools provide continuous visual support throughout the design and prototyping of new furniture solutions. Designers can automatically generate multiple product variants from a single initial concept, text input and/or image, facilitating the negotiation and validation of solutions with clients and commercial or technical departments. This application strengthens cross-departmental collaboration, enabling clear and effective communication through concrete and realistic product visualisations.

Material and Finish Selection Based on Specific Criteria

The ability of generative models to accurately simulate a wide range of materials and finishes offers a significant advantage to product designers, enabling them to work according to technical, functional and environmental criteria. These tools allow for immediate visualisation of how different materials can be applied to a single digital furniture design. Furthermore, these visualisations can be enriched with relevant data on variables such as carbon footprint, technical performance, or recyclability. This supports informed decision-making and enables the creation of proposals that are not only aesthetically appealing but also meet sustainability, functionality and manufacturing feasibility criteria.

Immersive Virtual Experiences for Prototype Validation

The combination of generative AI with immersive visualisation technologies—such as virtual and augmented reality—represents an emerging area of application with high potential for the furniture sector. The creation of immersive virtual environments allows for prototype visualisation in context and enables real-time adjustments to finishes or spatial layouts. This facilitates agile and well-informed technical and aesthetic decision-making. Virtual prototypes optimise the time and cost associated with physical model creation and significantly improve communication and negotiation capabilities with clients and manufacturing teams. [6]

Automation of Visual Technical Documentation

Repetitive tasks involved in preparing visual technical sheets, detailed plans and final renders can be automated using generative tools. This allows designers to focus on higher-value creative tasks, such as the visual development of new solutions, style exploration or the customisation of client proposals. Automation not only enhances visual consistency and accelerates the production of graphic documentation, but also expands the team's capacity to generate visual assets that enrich the project and add differentiation at every stage of the design process.

Implementation Aspects

■ Implementation difficulty: Medium

The use of generative AI tools such as Krea or VIZCOM comes with a low cost and allows teams to begin working with visual prototypes without major barriers. The level of difficulty increases with custom developments and more specialised environments like Stable Diffusion, which require greater technical and financial investment. Moreover, integrating these tools into existing workflows poses challenges within organisations. It is therefore essential to promote organisational transformation that reduces resistance to change, trains teams in how to use these tools and how to formulate effective prompts and encourages creative experimentation.

■ Economic viability: Medium-High

The investment required depends on the type of solution: using existing tools involves a low cost, while custom development requires a higher initial investment. Nonetheless, the return on investment (ROI) can be significant thanks to accelerated creative processes and a reduced need for physical furniture prototypes, which lowers the investment in time and materials. There are flexible options—from in-house solutions to external services—that make it possible to tailor spending to each company's level of digital maturity and internal capabilities.

■ Human factors

The integration of generative AI into creative workflows opens up new opportunities for professionals to focus on higher-value tasks. These tools automate repetitive work such as generating visual variants or producing graphical documentation, freeing up time for designers to explore innovative solutions, experiment with emerging styles or adapt proposals to specific contexts. They also enable a fluid dialogue between designer and machine, where the AI acts as a co-creator: it suggests, adjusts, and visualises, while the human makes strategic decisions, selects the best options and refines them with judgement. This collaborative approach not only improves productivity but also enhances applied creativity and the overall quality of the final output.
However, several challenges must be addressed to integrate this technology effectively. First, organisations must foster a cultural shift that positions AI as a trusted co-pilot, not a competitor.

This includes structured training in prompt engineering, critical interpretation of generated content, and the development of visual literacy to assess AI-assisted outcomes.

Equally important is addressing ethical implications: ensuring transparency about model capabilities and limitations, clarifying authorship of AI-generated assets, and documenting the origin and use of training data.

New roles may also emerge, such as "AI Design Strategist" or "Prompt Curator", requiring hybrid skill sets that combine creative direction with AI literacy.

Finally, open communication between HR, design, and IT teams is key to creating a safe and engaging adoption process, where feedback, experimentation, and continuous learning are encouraged.

A responsible, human-centred implementation ensures that AI enhances—not replaces—the creative professional, reinforcing their relevance and impact within a digitally transformed design process.

■ Environmental factors

When applied to furniture and interior design, generative AI can significantly reduce the environmental impact of creative and production processes. Digitally validating concepts, prototypes and materials before manufacturing reduces waste caused by errors or unnecessary testing and avoids the creation of physical waste. These technologies also enable the simulation of use scenarios, early assessment of sustainable design feasibility, and optimisation of production processes to lower energy consumption. In addition, they open new avenues for integrating circular economy principles such as modularity, reparability, and recyclability.

However, certain environmental impacts must be monitored. According to various sources, training advanced models can generate more than 500 tonnes of CO_2, and data centres consume large volumes of resources—up to 216 million litres of water per week for cooling. Furthermore, rapid hardware obsolescence could lead to an estimated 5 million tonnes of electronic waste by 2030.

In addition to electricity and water consumption, the hardware itself—primarily GPUs and specialized AI chips—is resource-intensive to manufacture. These devices contain rare earth elements and precious metals, such as cobalt, gold, and neodymium, contributing to environmental degradation and human rights concerns associated with mining. The frequent upgrading of hardware to accommodate larger models exacerbates electronic waste (e-waste) and shortens equipment life cycles.

In this regard, AI-based tools can support compliance with the Ecodesign Regulation (EU 2024/1781), which promotes the creation of durable and sustainable products. Likewise, the adoption of renewable energy in companies using AI—encouraged by Directive (EU) 2018/2001—can further reinforce the environmental benefits of these solutions. Moreover, the AI Act, effective as of August 2024, requires the environmental impact of AI to be assessed, promoting more responsible and transparent adoption. To deploy these technologies in an environmentally coherent way, it is recommended to select tools with lower energy demand, adapt their use to actual needs, and establish internal metrics to monitor ecological impact over time.

■ Alignment with certifications and regulations

In the furniture sector, generative AI can support CE marking compliance through digital simulations that verify conformity before production—especially in products subject to regulation, such as children's furniture or items with electrical components. It also enables the generation of accurate data for Environmental Product Declarations (EPDs), optimises material selection and estimates carbon footprint, helping companies comply with standards like ISO 14025 and meet the environmental certification requirements of public tenders and international markets.
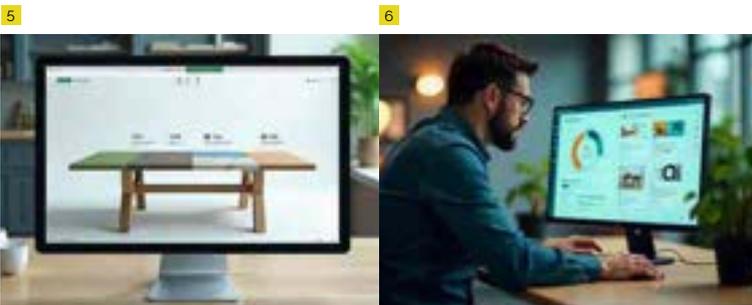
Generative AI for custom design and fast prototyping

Solutions

4o Image Generation
OpenAI
United States 🔗

OpenAI's 4o model enables the generation of highly realistic images from text prompts, sketches, or reference photos. It enhances creative workflows by allowing designers to rapidly visualize concepts and explore design alternatives without traditional 3D rendering or prototyping, significantly accelerating early-stage idea development in fields like furniture and product design.

Midjourney Image Generator
Midjourney
United States 🔗

Midjourney is a text-to-image generator known for producing stylized and artistic visuals from simple text inputs. It's widely used by designers and creatives to visualize mood boards, design atmospheres, and aesthetic concepts quickly, making it an efficient tool for brainstorming and early visualization in creative industries like furniture and industrial design.

Krea.ai Generative Platform
Krea.ai
United States 🔗

Krea.ai offers a generative design platform that transforms sketches, photos, or text into refined, high-quality images. Tailored for creative professionals, the tool supports fast visual ideation and variant generation, enabling designers to test multiple furniture design ideas in real-time, fostering innovation without engaging in manual rendering processes.

Vizcom Ai Prototyping Tool
Vizcom
United States 🔗

VIZCOM is an AI-powered tool designed for product prototyping through real-time image generation. By converting sketches or text into detailed visual representations, it empowers designers to rapidly iterate on product forms and features. Especially useful in industrial and furniture design, VIZCOM bridges early ideation and refined concept visualization.

AI-Powered Rendering Tool
Rendair
Spain 🔗

Rendair provides AI-driven rendering solutions that convert sketches, photos, and floor plans into high-quality visual content. It accelerates product development and space planning by offering cost-effective, rapid prototyping alternatives for furniture and interior design professionals

Stable Diffusion
Stability AI
United Kingdom 🔗

Stable Diffusion is an open-source image generation model that transforms text or images into photorealistic visuals. Its flexibility and control make it ideal for custom furniture or product prototyping, allowing designers to iterate on styles, materials, and forms without costly rendering tools or physical mock-ups, boosting creative experimentation and speed

Furniture Generator
OpenArt AI
United States 🔗

OpenArt AI Furniture Generator creates realistic furniture images from text prompts, photos, or sketches. It helps designers and manufacturers visualize products quickly, reducing prototyping costs and speeding up the creative process in furniture design by enabling rapid concept exploration without physical samples.

Visualize AI Platform
Visualize AI
India 🔗

Visualize AI offers an intuitive platform for generating detailed product and space renderings from sketches, photos, or floor plans. It supports furniture and interior designers by simplifying prototyping and accelerating visual content creation, enhancing decision-making and communication with clients and stakeholders.

AI Space Rendering Platform
Spacely AI
Thailand 🔗

Spacely AI specializes in generating photorealistic renderings of living spaces from images or text, helping designers visualize layouts and furniture arrangements. Its AI-driven approach reduces reliance on traditional rendering methods, saving time and costs in interior design and architectural projects.

AI Agent for Design
Oda AI
United States ⊂⊃

Oda AI Agent leverages artificial intelligence to create detailed product and space visualizations from various inputs, including sketches and text. It enhances the furniture and living spaces sector by streamlining prototyping processes and enabling rapid iteration of design concepts.

Visual Content Generation Platform
Presti AI
United States ⊂⊃

Presti AI enables the generation of realistic furniture and space renderings from text or images, aiding designers in fast prototyping and visualization. Its platform enhances creative workflows by reducing the need for physical samples and traditional rendering, boosting efficiency in design projects.

AI Rendering Application
Fermat
Spain ⊂⊃

Fermat's AI-powered app produces photorealistic product and space renderings from sketches, photos, or text descriptions. Focused on the furniture and interior design markets, it helps reduce prototyping time and costs while facilitating rapid concept visualization.

Context-Aware Interior Redesign Tool
Interior AI
United States ⊂⊃

Interior AI offers an AI-driven platform that redesigns interior spaces by suggesting furniture, styles, and layouts based on the existing context. It allows users to explore multiple furnishing scenarios instantly, enhancing creativity and decision-making in interior design projects.

AI Interior Design Assistant
RoomGPT
United States ⊂⊃

RoomGPT uses AI to generate various interior design alternatives based on user photos, proposing new furniture layouts and styles. This quick and easy tool supports homeowners and professionals in visualizing different furnishing options without manual redesign efforts

AI-Powered Interior Redesign Platform
REimagine Home
Canada ⊂⊃

REimagine Home leverages AI to offer context-aware interior redesign solutions. It suggests furniture, layouts, and styles tailored to the user's space, enabling rapid exploration of multiple furnishing scenarios and supporting informed design decisions with minimal effort.

AI Material and Finish Selection Tool
Polaron AI
United Kingdom ⊂⊃

Polaron AI specializes in AI-driven material and finish selection, optimizing choices based on aesthetic, technical, and environmental criteria. It complements interior design tools by helping professionals select the best materials for furniture and spaces, improving sustainability and design quality.

Generative AI for custom design and fast prototyping

Examples

Kartell
Italy

A furniture collection designed by the Kartell team in collaboration with generative AI, exploring new aesthetic and functional forms through human–machine co-creation in product design.

Studio Snoop
Australia

A design studio that features Tilly Talbot, a virtual designer powered by generative AI. Tilly collaborates with the human team to create new furniture pieces, including surreal stools that were manufactured and exhibited in 2023 as an example of co-creation between AI and designers.

StageInHome
Spain

A platform based on generative artificial intelligence that transforms real images of empty spaces into decorated proposals in various styles. It automatically generates both the furniture and the ambient setting, providing realistic visualisations that allow users to explore multiple design alternatives in seconds. Ideal for experimenting with layouts, styles and finishes without the need for manual renders.

Juliettes Interiors
United Kingdom

A company that brought to life the verbal request of a customer through a collaborative process that began with AI-generated concepts. These were developed into technical drawings and then manufactured by skilled artisans, resulting in a bespoke dining set that balanced innovation with practical design and high-quality craftsmanship.

Meridiani
Italy

A work in progress generative AI platform for interior design. The tool creates customised room visuals in real time, helping designers and clients accelerate and make the early project stages simpler while maintaining a strong focus on personalisation, creativity, and user experience.

HC28 Cosmo
China

The TWISTY MINI armchair by Roderick Vos for HC28 COSMO was inspired by AI-generated concept images. Its continuous looping form emerged from interpreting generative visuals into physical design. This sculptural piece exemplifies the dialogue between artificial intelligence and human creativity, translating abstract, algorithmic aesthetics into a playful, ergonomic furniture object.

Paola Lenti
Italy

Paola Lenti's 2025 "Alma" collection was co-created with Francisco Gomez Paz using generative algorithms. AI optimizes lightweight stainless-steel frames fabricated by CNC, enabling limitless custom sizes and sustainable padding-free seating, demonstrating industrial-scale personalization, shorter prototyping cycles and reduced materials and energy waste.

AI-driven knowledge management systems

13
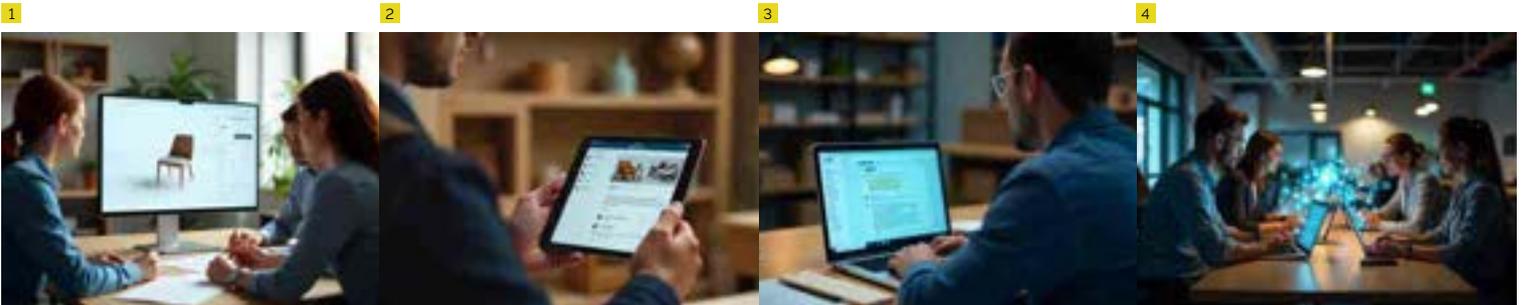
Implementation difficulty: **Medium**
Economic viability: **Medium-High**

AI-driven knowledge management systems

Description

Foundation models represent one of the most significant innovations in artificial intelligence in recent decades. Before their emergence, developing AI solutions to process complex texts or content required training models from scratch—a costly and time-consuming process. Thanks to their versatility and adaptability, foundation models (like GPT, PaLM, Claude) enable companies to achieve tangible results with a lower initial investment than that required for conventional AI developments. This makes it easier to explore real-world use cases without the need for substantial upfront resources.

Large Language Models (LLMs), in particular, have become a cornerstone technology within the foundation model landscape. Trained on massive volumes of text, these models are capable of understanding, process and generate human-like text, generating coherent content and adapting to a wide range of contexts. When combined with other AI techniques, these solutions enable fast, conversational and accurate interaction with corporate documentation—regardless of the format in which it is stored—and are transforming the way organisations manage, query and share internal knowledge. [1]

Adopting this technology in the furniture and habitat sector provides a strategic tool to optimise document management, internal training and regulatory compliance. LLMs allow key information to be extracted from manuals, standards, technical datasheets and any other documentation, making organisational knowledge more accessible and contextualised. This not only reduces the time spent searching for information but also improves decision-making accuracy and supports operational continuity across teams. [2]

One of the most powerful ways to apply this technology is through so-called knowledge assistants: conversational systems that connect to internal information sources (databases, technical documents, intranets or cloud platforms) and return specific answers tailored to the user's context. These assistants allow users to query procedures, manufacturing regulations or product technical specifications without manually checking each information source. The result is a seamless and natural experience that facilitates adoption at all levels of the organisation, from shop floor workers to quality or product development managers.

These solutions are built on scalable infrastructures that use APIs and cloud services, making them easy to integrate with existing systems and adaptable to each company's size and digital maturity. They are also designed with a human-in-the-loop approach, where users interact with, validate and fine-tune the system's outputs. This not only increases the accuracy and reliability of responses but ensures that the solution remains aligned with the team's real needs—maintaining a balance between automation and human oversight. [3]

Applications in the furniture sector are wide-ranging and concrete: document analysis for design or production processes, support for regulatory compliance in product certifications, internal assistance in quality assurance workflows, or even automated technical support for clients and distributors. In an environment where information is abundant yet fragmented, this technology positions itself as a key ally for making corporate knowledge more accessible, structured and useful.

As we will see in the following sections, the impact of this technology goes beyond automation: it lies in its capacity to foster a more connected, efficient, and knowledge-centred organisational culture.
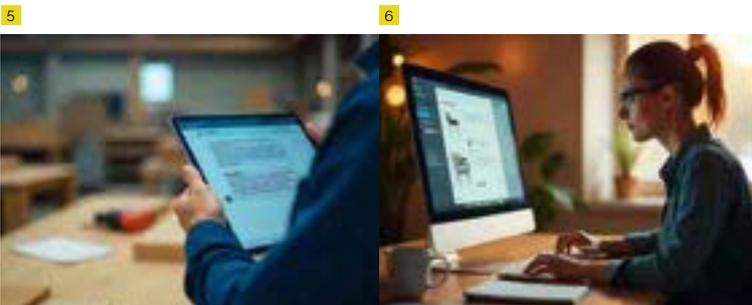
AI-driven knowledge management systems

Application

Generative AI applied to knowledge management in the furniture sector enables companies to organise, query and extract information quickly from complex business documentation—such as internal procedures, manuals, quality management protocols or details about public tenders—streamlining the work of various roles across departments. [4]

Intelligent Access to and Organisation of Corporate Knowledge

Generative AI acts as a bridge between departments such as design, engineering, production and sales, facilitating access to key documentation: internal procedures, technical manuals, assembly instructions and more. This improves knowledge transfer between teams and accelerates onboarding, especially valuable for furniture companies with complex processes or high staff turnover. It also empowers administrative or management profiles to retrieve information without relying on technical staff. [5]

AI Assistant for Quality Management Systems

Integrated into quality platforms, the assistant can assist in querying protocols, accessing technical documentation, locating similar incidents or retrieving non-conformity records. Quality managers and plant technicians can thus optimise document management, reduce errors and streamline inspection, audit and continuous improvement processes.

Automated Analysis of Tenders and Contracts

Generative AI-based assistants can extract and summarise key information from public tenders or complex contracts—budgets, deadlines, technical requirements or regulatory clauses. This functionality is particularly useful for roles such as procurement managers, commercial directors or technical staff who need to quickly assess the feasibility of a proposal without manually reviewing extensive documents. [6]

Analysis of Corporate Social Responsibility (CSR) Documentation

AI knowledge management systems can automatically identify relevant information in sustainability or environmental and social regulatory documents. They assist quality, sustainability or compliance departments in analysing key indicators related to materials, labour conditions, emissions, circular economy practices, and more. This facilitates reporting and helps meet client or certification requirements.

Implementation Aspects

Implementation difficulty: Medium

The level of difficulty depends on how the technology is used, ranging from simple queries with ChatGPT, which require little technical expertise, to advanced developments involving multi-agent systems, integration with other technologies and fine-tuned prompts. Deep integrations with systems like ERP or CAD increase both complexity and cost, and adoption also requires a cultural shift, including team training and human-in-the-loop validation. To ensure secure and effective use, companies should consider data governance measures, such as access control, anonymisation and encryption, and adapt models to the specific vocabulary, workflows and compliance standards of the furniture industry through fine-tuning, custom embeddings or internal documentation.

Economic viability: Medium-High

The use of existing market solutions, which connect easily with other digital tools via standard integration systems, offers an accessible entry point with low upfront costs. Investment increases when a higher degree of customisation or integration with internal systems is required. In return, these tools significantly reduce the time and resources spent on manual tasks, improve decision-making, and enhance operational efficiency. Moreover, the system is scalable and adaptable to organisational growth and specific business needs.

Human factors

The adoption of knowledge assistants and generative AI tools transforms how teams access, manage and consult internal information. By automating repetitive tasks—such as manually searching for documents, interpreting regulations or reviewing procedures—these solutions free up time for professionals to focus on higher-value activities: continuous improvement, process analysis, complex problem solving, and strategic decision-making. This redistribution of time supports a more efficient and collaborative culture, where individuals act as supervisors, interpreters and amplifiers of organisational knowledge. They shift from "information retrievers" to "knowledge curators", playing a key role in improving data quality and decision readiness.

In addition, by simplifying access to regulations, manuals and complex procedures through natural language interaction, these tools enhance cognitive accessibility and help integrate non-technical profiles into key management processes.

This is particularly valuable for onboarding new employees or involving profiles from HR, legal, or sustainability departments in technical matters.

While these tools are designed to be intuitive, effective adoption requires structured onboarding programmes and hands-on workshops tailored to diverse roles.

Teams must be equipped with prompt literacy, domain-specific query formulation techniques, and the ability to critically assess AI-generated content.

Fostering these competencies not only improves the quality of interactions with the system but also strengthens user autonomy, digital maturity, and cross-functional collaboration.

Successfully embedding generative AI into knowledge workflows requires a cultural shift—championed by leadership and HR—towards continuous learning, trust in human-AI co-creation, and alignment with organisational goals.

Dedicated AI champions, peer learning networks, and transparent communication about capabilities and limitations further support adoption.

■ Environmental factors

AI-based knowledge assistants contribute to more sustainable document management by reducing the need to print manuals, reports or technical datasheets. Digital querying eliminates the use of paper, binding materials and physical storage media such as folders, external drives or USB sticks. Centralising information in digital environments also reduces reliance on printers and physical storage, lowering energy consumption and the environmental footprint in office and industrial settings. Real-time content updates, version control and the avoidance of outdated documents improve traceability and optimise the use of digital resources.

These solutions also reduce duplication of effort and materials by facilitating access to existing internal standards, procedures or reports—saving time and resources in document creation. However, it is important to consider that running AI models also increases energy consumption, both from training processes and ongoing digital infrastructure use.

The training phase of these assistants is one of the most environmentally burdensome aspects. Training a large language model (LLM) like GPT-4 involves billions of parameters and petabytes of text data, requiring millions of GPU-hours in high-performance computing (HPC) environments. This process consumes vast amounts of electricity and water and produces significant carbon emissions, especially when powered by fossil-fuel-dominated energy grids.

The hardware required to train and run these models—such as GPUs, TPUs, and supporting servers—is also a major source of environmental impact, because these components depend on rare earth elements and high-purity silicon. Additionally, the pace of innovation in AI hardware leads to short upgrade cycles, compounding resource extraction and disposal issues (e-waste).

Once deployed, AI assistants require substantial computational resources to serve user queries in real time. These systems are typically hosted on cloud platforms and data centers, which contribute to the growing electricity demand and environmental impact of the digital sector. Moreover, AI assistants rely on data storage, retrieval, and integration across vast knowledge bases, further increasing demand for digital infrastructure.

Still, the benefits in terms of efficiency, digitalisation and reduced reliance on physical media help offset part of this impact, especially when best practices are followed and organisations move towards energy-efficient technological environments.

■ Alignment with certifications and regulations

Generative AI-based solutions must comply with the General Data Protection Regulation (GDPR) and can support the implementation of standards such as ISO 9001 (Quality Management Systems), ISO 14001 (Environmental Management), and ISO 26000 (Social Responsibility). They promote more efficient, secure and traceable knowledge management, ensuring access control, transparency and alignment with corporate values and the management systems adopted within the sector.

AI-driven knowledge management systems

Solutions

Bidbrief – Tender Management System
Sciling
Spain ⊖

Bidbrief is a solution developed by Sciling that uses AI agents to analyse tender specifications and technical documentation. This tool can support manufacturing companies in speeding up decision-making around participation in tenders or other public procurement and funding processes.

Document Intelligence
SambaNova
United States ⊖

SambaNova Document Intelligence leverages generative and conventional AI to provide conversational access to technical and operational documents. It helps furniture companies analyze, classify, and query regulations, manuals, and invoices, automating document workflows and supporting onsite technical staff to improve compliance and reduce query time.

Intelligent Document Processing (IDP)
Appian
United States ⊖

Appian's Intelligent Document Processing combines AI technologies to automate the extraction, classification, and querying of technical documentation such as SOPs, manuals, and datasheets. Its integration with enterprise systems enhances operational efficiency, enabling faster internal support and ensuring regulatory compliance in the furniture industry.

Squint.ai Copilot
Squint.ai
United States ⊖

Squint.ai Copilot uses a blend of generative and traditional AI to offer conversational interaction with technical and operational documents. It enables quick data retrieval and validation for furniture sector workflows, automating document analysis and providing on-site assistance to staff, thereby improving compliance and reducing manual workload.

Eddy (AI-Powered Knowledge Management)
Document360
United Kingdom ⊖

Eddy by Document360 applies generative AI and conversational assistants to enhance access to internal knowledge. It enables quick querying of technical documents, regulations, and procedures, supporting onboarding, issue resolution, and compliance in furniture and manufacturing sectors, thereby improving knowledge management and operational efficiency.

Navex AI Assistant
Navex
United States ⊖

Navex AI Assistant utilizes AI to streamline access to compliance-related documents and internal knowledge. It supports furniture companies in navigating regulations and quality standards, facilitating faster issue resolution, employee onboarding, and ensuring adherence to internal policies through conversational AI interactions.

AI-Powered Knowledge Platform
Sinequa
France ⊖

Sinequa offers an AI-driven knowledge platform that leverages generative AI to provide fast and contextual access to enterprise information. It helps furniture sector companies quickly query technical documents and internal data, accelerating decision-making and enhancing compliance and knowledge sharing across teams.

AI Knowledge Search and Insights
Mindbreeze
Austria ⊖

Mindbreeze provides AI-powered search and knowledge insights, enabling companies to access and analyze technical documents, regulations, and procedures. Its conversational assistants improve internal knowledge retrieval, supporting onboarding and compliance processes in furniture manufacturing and related industries.

AI Knowledge Management Platform
Zive
United States ⊖

Zive integrates generative AI and conversational tools to facilitate quick access to internal knowledge and documents. It supports furniture sector companies by improving the efficiency of information retrieval, aiding in issue resolution, compliance adherence, and smoother onboarding experiences.

Thron AI Knowledge Platform
Thron
Italy ↩

Thron's AI platform enhances knowledge management by enabling instant access to company documents, contracts, and procedures. Its AI assistants help furniture industry professionals quickly find relevant information, ensuring compliance and supporting operational efficiency through intelligent data organization.

Guru Knowledge Management
Guru
United States ↩

Guru leverages AI and conversational assistants to improve knowledge sharing and retrieval within organizations. It enables furniture companies to access technical documents, regulations, and best practices instantly, facilitating faster onboarding, issue resolution, and quality standard compliance.

Work AI Platform
Glean
United States ↩

Glean's Work AI Platform uses generative AI to provide conversational access to enterprise knowledge. It helps furniture sector professionals quickly find documents, regulations, and procedures, supporting efficient onboarding, compliance, and internal communication through seamless information discovery.

SquirroGPT AI Platform
Squirro
Switzerland ↩

SquirroGPT combines generative AI and data analytics to enhance knowledge management. It offers furniture industry companies conversational access to internal documentation and insights, streamlining compliance, technical support, and decision-making by surfacing relevant information quickly and contextually.

Dynamic Expertise Graph
Starmind
Switzerland ↩

Starmind builds dynamic expertise graphs by analyzing communications from emails, Jira, and Teams to route internal questions to the right experts. Widely used in manufacturing and R&D, it accelerates problem-solving and knowledge sharing while ensuring GDPR compliance, benefiting furniture sector workflows.

Einstein 1 Platform
Salesforce
United States ↩

Salesforce Einstein 1 integrates AI across company data and workflows using low-code tools. It automates tasks and delivers personalized insights, enhancing sales and knowledge management efficiency. Furniture companies benefit from streamlined processes and improved customer engagement through AI-powered data connectivity.

Zoho CRM with Zia AI
Zoho
India ↩

Zoho CRM powered by Zia AI predicts lead outcomes, suggests optimal contact times, generates personalized messages, and provides performance reports. This AI-enhanced CRM helps furniture sector sales teams boost efficiency, reduce operational costs, and improve customer relationship management through data-driven automation.

Open-Source Framework for AI Development
LangChain
N/A (Open-Source) ↩

LangChain is an open-source framework that enables companies to build, customize, and integrate AI applications with greater control over data and workflows. It supports the development of advanced language models and AI tools, helping organizations reduce vendor lock-in and foster in-house innovation.

Open-Source NLP Framework
Haystack
N/A (Open-Source) ↩

Haystack is an open-source NLP framework designed for building scalable document search and question-answering systems. It allows companies to create customizable AI solutions for deep document understanding, reducing reliance on commercial vendors and enabling tailored integration with existing IT infrastructure.

Open-Source Large Language Model
LLaMA
N/A (Open-Source) ↩

LLaMA, developed my Meta AI, is an open-source large language model providing organizations with the ability to run advanced AI language processing on their own infrastructure. It offers flexibility, enhanced data privacy, and customization opportunities to reduce dependency on commercial AI providers.

AI-driven knowledge management systems

Open-Source Large Language Model
Mistral
N/A (Open-Source) ⌐⊃

Mistral is an open-source large language model focused on delivering powerful language understanding capabilities. It supports enterprises seeking customizable AI tools with full control over their data and AI processes, minimizing vendor lock-in risks and fostering innovation.

Retrieval-Augmented Generation (RAG) Engine
RAGFlow
China ⌐⊃

RAGFlow is an open-source engine specialized in Retrieval-Augmented Generation, enabling deep understanding of complex documents like PDFs, images, and databases. It delivers citation-backed AI responses and integrates smoothly into business workflows through intuitive APIs, empowering companies to manage knowledge with full data control.

Examples

IKEA
Sweden
⌐⊃

IKEA AI Assistant (ChatGPT) and Kreative: IKEA combines conversational AI with immersive design tools to enhance customer experience. Its AI Assistant (built on ChatGPT) helps users and employees with product queries, furniture recommendations and decoration advice, offering quick access to technical and commercial information. In parallel, IKEA Kreativ enables customers to scan their own spaces, remove existing furniture and virtually place IKEA products at real scale and lighting. Using AI, 3D scanning and AR, the tool creates editable room models that support realistic and personalised design decisions.

Wayfair
United States
⌐⊃

Agent Co-Pilot: An internal assistant powered by generative AI that provides instant answers to sales and customer support staff on products, policies and alternatives—enhancing support efficiency and quality.

Freedom Furniture - Coveo AI-Powered Merchandising Hub
Australia
⌐⊃

Freedom Furniture utilizes Coveo's AI-powered merchandising hub to enhance product discovery and streamline knowledge management. This solution combines artificial intelligence with manual controls, enabling the company to efficiently manage product information and improve customer experience through intuitive search and personalized recommendations.

Steelcase – "Onboarding AI"
United States
⌐⊃

Uses Salesforce Einstein to unify data across Herman Miller, Knoll, and DWR; AI recommends products and surfaces cross-brand insights, improving customer service and merchandiser decisions.

Qatalog
United Kingdom
🔗

A knowledge management tool that uses artificial intelligence to enable teams to search and get answers in real time from all corporate sources (e.g. documents, tools, apps) without copying or moving data. It works as a conversational assistant that links information directly to the source, ensuring security, accuracy and constant updates.

Netguru Memory
Poland
🔗

An AI-powered knowledge base developed in-house as a centralised repository that stores, organises and shares knowledge within a company. The tool leverages artificial intelligence and machine learning to help quickly search huge databases and put together AI-generated case studies for internal and external purposes.

HomeDepot
United States
🔗

Magic Apron is Home Depot's generative AI tool suite helping customers with home improvement projects. Available on their app and website, it's powered by proprietary knowledge combining datasets with Home Depot's expertise. It answers questions related to products, summarizes reviews, and acts like a digital store associate.

Optimizing marketing and sales processes with Generative AI: automation and personalization of contents

14

Implementation difficulty: **Medium**
Economic viability: **Medium-High**

Optimizing marketing and sales processes with Generative AI: automation and personalization of contents

Description

Generative artificial intelligence applied to content automation and personalisation combines text, image, audio and video models trained on large volumes of data to generate new content from simple instructions or contextual data. These technologies have evolved from foundation models such as GPT, Stable Diffusion, and video synthesis tools like Synthesia, and represent one of the most active areas of development in marketing and digital communication. However, despite their potential, these technologies also raise important concerns. One of the main challenges is the quality and reliability of the generated content, as generative models are prone to introducing inaccuracies or so-called "hallucinations"—plausible but incorrect outputs that can undermine trust. Additionally, the use of external datasets to train these models has sparked debate around copyright and intellectual property, particularly when the generated content replicates or is inspired by protected works without clear attribution or licensing. Companies should be aware that models trained on copyrighted images/text may generate derivative works and expose themselves to infringement claims.

In the context of the furniture sector, this technology enables the automatic generation of social media posts, advertising copy, visual catalogues, product videos and personalised text or audio messages tailored to different customer profiles, languages or preferences. Tools such as ChatGPT/DALL·E, Stable Diffusion, Runway or Synthesia can be used to produce creative, coherent and visually impactful assets for marketing campaigns. Furthermore, this automation allows for large-scale A/B testing, the adaptation of creatives to specific markets, and quick responses to shifts in trends or aesthetic preferences. [1]

One of the most strategic applications of generative AI in marketing and sales is the creation of tailored multimedia content—text, images, videos or audio—based on the analysis of visual trends, styles and product lines. These systems are designed to detect stylistic patterns in product databases, social media, trade fairs or internal materials, and translate them into proposals aligned with the brand's visual identity and the preferences of the target audience. This makes it possible to generate highly relevant and adaptable content for diverse commercial contexts.

In addition, generative AI drives new forms of interaction with customers through commercial content in dynamic interfaces, such as immersive experiences, visual rec-ommendations or interactive catalogues. These solutions present products, answer frequently asked questions or guide customers through the decision-making process in a visual, agile and contextualised way, enriching the experience across digital channels. [2]

From a strategic perspective, these capabilities enable furniture brands to increase visibility, build stronger emotional connections with customers, and improve purchase intent through persuasive, creative and personalised content. Moreover, by centralising style and messaging control within a single tool, brands can ensure consistent production of materials across multiple formats and channels, reinforcing the perceived value of the brand. [3]

A key advantage of this technology is its integration with standard marketing and sales tools such as content managers, automation platforms, visual editors or CRMs. This allows generative AI to be incorporated into existing workflows within commercial processes in the furniture industry, without the need for radical changes to current structures, maintaining creative control while leveraging the power of automation.

As the following sections will show, these solutions are becoming key tools for amplifying creativity in sales processes, enhancing customer experience, and strengthening the furniture sector's competitiveness in an increasingly dynamic digital environment.

Application

The integration of generative artificial intelligence into marketing and sales processes in the furniture sector allows for the automation and scaling of key tasks in a highly personalised and efficient manner. Below are the main applications:

Creation, Management and Strategy of Personalised Content

Marketing teams can automatically generate visual, textual and audiovisual materials tailored to different customer profiles, channels and commercial contexts. Based on simple prompts, brand style guides, or visual analyses of style lines, product trends or competitor campaigns, it is possible to create content aligned with the strategic goals of each campaign. This information can also be used to redefine positioning, adjust ongoing campaigns or identify market opportunities ahead of the competition. These tools ensure visual and narrative consistency without overburdening human resources.

However content effectiveness should be continuously assessed via analytics, feeding insights back into prompt engineering or model fine-tuning to ensure ongoing campaign relevance.

Despite process automation, every optimisation has to be validated by a team in terms of language, visual consistency and adherence to corporate values. The risk is that the additional workload for quality control partially nullifies the expected time savings. Although AI can produce content consistent with prompts and guidelines, it often lacks the creative, emotional or cultural depth that a human team can offer. The risk is that automatically generated content can come across as "flat" or stereotypical, reducing brand distinctiveness. [4]

Campaign and Marketing Workflow Automation

By integrating with email marketing platforms, CRMs or social media, it is possible to design automated communication workflows with dynamically generated messages. Generative AI can write personalised emails, create posts tailored to each platform and segment messages based on previously analysed audience behaviour. In addition, virtual assistants can offer instant and personalised support, answer frequently asked questions, and guide customers through the decision-making process. The use of virtual assistants also involves regulatory considerations. Under GDPR, users should be informed when interacting with AI, and any personal data processed must comply with transparency and consent requirements.

Many solutions (e.g. for social posts, product cards or catalogues) are based on standardised layouts, risking standardising the visual communication of brands. This would lead to a loss of originality and confusion with competitors using the same tools. [5]

Continuous Campaign and Content Optimisation

Through the automated analysis of performance metrics (click-through rates, engagement, conversions, etc.), generative models can suggest real-time adjustments to improve campaign effectiveness. This includes redesign suggestions for creatives, modifications to advertising copy or changes to distribution frequency and channels. The ability to perform large-scale, automated A/B testing enhances data-driven decision-making and supports continuous learning within the team.

Acceleration of Marketing Asset Production

The automatic generation of advertising copy, product sheets, visual creatives and audiovisual assets enables content production to scale without compromising quality. This capability is especially valuable in fast-moving campaign environments or in multilingual, multi-country markets, where adapting content across languages and regions can be automated while maintaining brand consistency. Rather than replacing creative professionals, generative AI is best understood as a tool that enhances their capabilities. Human input remains essential to guide, supervise and refine outputs, ensuring relevance, accuracy and alignment with brand values. Collaboration between humans and machines allows content creators, designers and marketing strategists to focus on higher-value tasks, combining automation with strategic creativity. [6]

Implementation Aspects

Implementation difficulty: Medium

The complexity of implementation varies depending on the chosen solution. Integrating off-the-shelf tools with prebuilt functionalities is generally straightforward, while custom developments or complex integrations require greater technical effort. Additionally, success depends on cultivating a data- and results-oriented culture, managing information sources effectively, and integrating AI with existing marketing and sales systems. Adapting teams to new processes and workflows also presents an important organisational challenge.

Economic viability: Medium-High

The cost of implementation depends on the level of customisation and integration needed. Affordable options are available through cloud-based services and SaaS subscriptions, allowing companies to start with moderate investments. The greater the degree of segmentation and automation, the higher the potential return on investment. However, large-scale projects or complex integrations (e.g. with CRM, CMS or internal systems) will increase initial costs, though they may also lead to improved competitiveness in the long term.

Human factors

The adoption of generative artificial intelligence in marketing and sales can significantly improve the work experience of teams by freeing them from repetitive tasks such as writing promotional content or manually producing creatives. This automation enables professionals to focus on strategic decisions and, above all, higher-value creative work—fostering a culture of co-creation where the human curates, validates and supervises the content generated by AI.

This shift enhances job satisfaction and allows communication professionals to concentrate on storytelling, brand building, and market innovation.

To ensure this transformation is effective, it must be supported by a comprehensive upskilling strategy that equips teams to use these tools, refine outputs, main-

tain brand coherence, and participate proactively in an evolving digital environment.

This includes training in prompt engineering, ethical content generation, brand-safe adaptations and data literacy for campaign optimisation.

At the same time, it is important to be mindful that the abundance of automatically generated content can lead to choice fatigue, reduce message relevance or dilute brand differentiation if not applied with care.

Strengthening editorial judgement and implementing content governance frameworks help filter outputs and ensure alignment with campaign goals.

Encouraging critical engagement with AI-generated content fosters purposeful selection and protects brand identity from generic or misaligned outputs.

Likewise, aligning the use of these technologies with the organisation's values and objectives ensures a deployment that is ethical, transparent and consistent with the sector's social responsibility.

In practice, this means involving marketing, legal and HR departments in AI adoption, ensuring transparency in tool use, and clarifying the role of AI in content creation to both teams and audiences.

◼ Environmental factors

The use of generative artificial intelligence in marketing and sales can contribute significantly to the operational sustainability of furniture companies. With improved audience segmentation and the ability to generate personalised materials without physical photoshoots, it becomes possible to reduce the production and distribution of printed catalogues, brochures or promotional materials that often go unused. This efficiency not only reduces the consumption of paper, packaging and physical media, but also cuts down the time and costs associated with organising complex productions.

Moreover, presenting products virtually and generating visual and audiovisual content without travel lowers the carbon footprint associated with business trips or participation in promotional events—a particularly relevant factor in a sector where commercial cycles often require intensive mobility. Centralised digital workflows, through platforms connected to tools such as CRMs or CMSs, further minimise the need for physical infrastructure

and materials, supporting a more agile and sustainable communication strategy.

That said, while these benefits are clear, the implementation of these tools must be coherent and avoid greenwashing. In a context where AI-generated visuals may appear sustainable due to their digital nature, it is important to consider the environmental cost behind the infrastructure that powers them—particularly in cloud-based generative systems.

Although furniture companies typically use pre-trained, ready-to-deploy AI solutions, these still rely on large models hosted in energy-intensive global data centres. The training and continuous operation of such models demand high computational power, with frequent inference, personalisation processes and recommendation algorithms running at scale. This entails considerable energy and water consumption.

Hardware also plays a role: the GPUs, TPUs and custom AI chips required for real-time content generation are built with rare materials like cobalt or neodymium, whose extraction carries environmental and social risks. In addition, ongoing performance demands lead to frequent hardware upgrades, contributing to electronic waste.

To ensure real sustainability gains, furniture companies should favour technology providers with clear energy-efficiency strategies, responsible sourcing policies, and transparent reporting on environmental impact—aligning their communication efforts with real, measurable action.

◼ Alignment with certifications and regulations

Generative AI solutions used in marketing and sales must comply with the General Data Protection Regulation (GDPR), especially when personal data is used for segmentation or personalisation. They must also align with the transparency requirements of the European AI Act, which mandates the identification of AI-generated content when it influences consumer decisions or perceptions. Furthermore, respect for copyright and consistency with the company's ethical and communication values must be guaranteed.
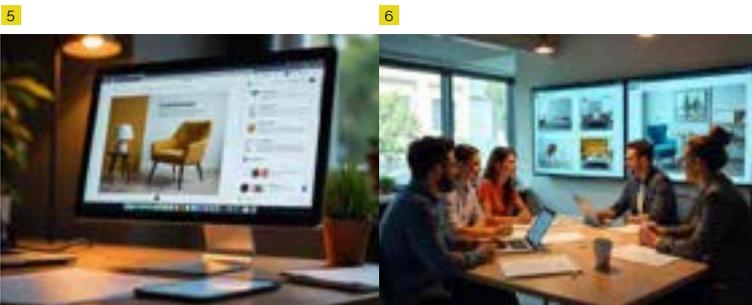
Optimizing marketing and sales processes with Generative AI: automation and personalization of contents

Solutions

AI-Generated Hyper-Realistic Lifestyle Scenes
Scenes
Denmark

Scenes leverages AI to create hyper-realistic lifestyle scenes for the furniture sector, eliminating the need for traditional photoshoots. Their solution helps brands produce versatile, attractive product presentations that enhance marketing materials and digital showcases efficiently and cost-effectively.

AI-Powered Ad Testing and Campaign Evaluation
Kantar
United Kingdom

Kantar's AI-driven Ad Testing platform predicts the effectiveness of videos and banner ads before launch. This tool helps manufacturers and brands optimize campaigns based on data-driven insights, reducing creative validation time and improving advertising impact for better marketing results.

AI-Powered Visual Generation Platform
Presti.ai
France

Presti.ai offers an AI-driven platform that generates hyper-realistic lifestyle images for furniture product presentation. It enables brands to create compelling visual content without physical photoshoots, supporting marketing campaigns with versatile, photorealistic imagery that engages customers across digital channels.

AI-Driven Multimodal Campaign Creation and Optimization
Typeface Arc Agents
United States

Typeface Arc Agents act as intelligent, always-on teammates that ideate, create, and optimize multimodal marketing campaigns. They ensure copy and imagery remain aligned with brand guidelines, boosting creativity and campaign effectiveness through AI-driven content management.

AI-Generated Interior Scenes
Freepik
Spain

Freepik provides AI-generated interior scenes ideal for catalogues, social media, and advertising campaigns. Their extensive library of photorealistic visuals supports furniture companies in creating appealing marketing content quickly, helping brands boost customer engagement and showcase products attractively.

Automated Visual Ad and Copy Generation
AdCreative.ai
France

AdCreative.ai uses AI to automatically generate visual advertisements, promotional copy, and social media posts tailored to various formats and target audiences. It streamlines marketing workflows, helping brands create effective, engaging campaigns quickly while adapting content for maximum impact.

AI Content Creation Platform
Jasper
United States

Jasper is an AI-powered platform that automates the creation of promotional text, ads, and social media content. It helps businesses generate tailored copy for diverse audiences and formats, enhancing content marketing efficiency and creativity without manual effort.

3D Visualization and Product Customization Platform
Cylindo (Chaos)
Germany

Cylindo offers advanced 3D visualization, augmented reality, and real-time product customization tailored for furniture manufacturers and retailers. Their platform automates rendering and enables customers to personalize products by colors, finishes, and materials, enhancing e-commerce experiences and driving higher conversion rates.

Automated Content Generation
Contents.com
Italy

Contents.com leverages AI to produce visual ads and written promotional material automatically. Its platform adapts content for different media formats and audiences, enabling brands to scale marketing efforts and maintain consistent, high-quality messaging efficiently.

Brand Messaging Alignment Platform
Jacquard
United Kingdom 🔗

Jacquard helps companies maintain messaging consistency by aligning all marketing content with brand identity. Their platform ensures that ads, posts, and promotional materials reflect the brand's tone and values, supporting coherent and trustworthy communication across channels.

Empathic and Personalized Copywriting Platform
Anyword
United States 🔗

Anyword is an AI copywriting platform that customizes tone and style according to audience, product, and communication channel. It generates tailored content from product descriptions to advertising messages, addressing diverse profiles such as end users, architects, and distributors to maximize engagement.

Multilingual Marketing and CRM Messaging
Typewise AI
Switzerland 🔗

Typewise AI helps marketing and CRM teams craft multilingual messages that adapt tone and content for different audiences. This solution is especially valuable for international brands seeking consistent and coherent communication across diverse markets, improving customer engagement and brand unity.

Post-Purchase Customer Communication Automation
Auralis AI
United States 🔗

Auralis AI automates post-purchase communication by generating personalized responses, suggesting tailored content related to care, matching, and renewals, and assisting operators in real time. It integrates with CRM and e-commerce platforms to enhance customer experience, reduce operational costs, and foster loyalty.

AI-Generated Sales and Customer Service Emails
Flowrite
Finland 🔗

Flowrite generates sales emails, follow-ups, and replies from short prompts, supporting marketing and customer service teams. It ensures consistent messaging while saving time, streamlining communication workflows and enhancing responsiveness across customer touchpoints.

Optimizing marketing and sales processes with Generative AI: automation and personalization of contents

Examples

Hypotenuse AI
United States

Hypotenuse AI is a generative AI content creation platform for eCommerce. It enables the generation of high-volume product descriptions, ensuring that each text is unique—even for very similar items. This addresses a common need in the furniture sector, where products often come in multiple variants. Living Spaces, a major furniture retailer in the United States, uses this platform to create compelling, accurate, search-optimised, and brand-consistent product content at scale—effectively managing extensive catalogues.

Norr11
Denmark

The Danish brand Norr11 used Scenes technology to generate hyper-realistic images of its FAVE Lounge Chair without photoshoots. The "My FAVE Spot" project allowed for visuals aligned with brand identity, streamlining content production for catalogues, social media and e-commerce in the furniture industry.

Renovai
Israel

Renovai offers a suite of AI-driven e-commerce solutions for the furniture sector, including visual similarity search, product combination generators, personalised shopping assistants and recommendation engines that enhance customer experience and increase conversion rates.

Archiproducts
Italy

Archiproducts uses generative AI to improve searching with product discovery by enabling users to search for furniture using specific text. This tool makes the selection process straightforward, allowing professionals and consumers to find design solutions more efficiently, thus improving the overall user experience and engagement.

Alias Design
Italy

Alias Design uses the THRON platform to optimise their digital content management processes. It automates the creation of marketing content, product catalogues and technical datasheets.

Arper
Italy

Arper has integrated the THRON platform as a key tool in its B2B communication strategy, improving the experience of clients and partners via its website.

Lago
Italy

Lago has implemented several features of the THRON platform to centralise content management and distribution, achieving a 75% reduction in total digital assets by eliminating duplicates and improving traceability.

Serax
Belgium

Serax, a Belgian design and furniture company, adopted SAP Business AI to automate the processing of PDF-based orders. This reduced manual data entry by 33%, significantly improving operational efficiency. As a result, the team was able to focus on value-added activities such as upselling and personalized customer care.

Anyword
United States

Anyword is an AI-based copywriting platform that allows the tone and style of content to be customised according to the target audience. It is used by companies such as National Geographic and Red Bull to generate texts ranging from product descriptions to advertising messages, adapting to the preferences and emotions of the target audience.

Amazon Personalize
United States

Amazon Personalize leverages generative artificial intelligence to deliver personalised recommendations, dynamic content and tailored interactions, enhancing the customer experience in e-commerce.

Softology
United Kingdom

Softology introduced visual search tools that allow customers to upload images (photos, screenshots, magazine clippings) to find similar products in the catalogue. This functionality enhances the product discovery experience and increases customer engagement.

Smart Decision-Making in the Furniture Sector Through Data Correlation and AI-Powered Analytics

Implementation difficulty: **Medium**
Economic viability: **High**

Smart Decision-Making in the Furniture Sector Through Data Correlation and AI-Powered Analytics

Description

In the era of Industry 5.0, the integration of advanced analytics and artificial intelligence (AI) into manufacturing processes has become pivotal. AI-powered Decision Support Systems (DSS) and data correlation analytics enable manufacturers to transform vast amounts of data into actionable insights, facilitating informed decision-making and operational efficiency. These systems typically combine descriptive insight with predictive forecasting and, in some cases, prescriptive capabilities to support real-time decision-making.

These technologies harness machine learning algorithms to analyze data from various sources—production lines, supply chains, customer feedback, and market trends. By identifying patterns and correlations, DSS can predict outcomes, optimize processes, and recommend strategic actions. For instance, correlating production data with customer feedback can highlight areas for product improvement, while analyzing supply chain data can identify potential disruptions before they impact operations.

Implementing such systems requires a robust data infrastructure, including data collection mechanisms (sensors, IoT devices), data storage solutions, and analytical tools. The integration of these components allows for real-time monitoring and analysis, ensuring that decisions are based on the most current information available.

Moreover, the adaptability of AI-powered DSS means they can learn and evolve over time. As more data is collected, the system's predictive accuracy and decision-making capabilities improve, leading to continuous enhancement of manufacturing processes.

1 *Supply chain forecasting dashboard example*
2 *Dashboard used in furniture manufactory*
3 *Manufacturing optimization based on analytics, decision and IA flow* 🔗
4 *Manufacturing production management dashboard example* 🔗

Application

The furniture industry, characterized by its diverse product ranges and customization demands, stands to benefit significantly from AI-powered DSS and data correlation analytics. These technologies can be applied in various aspects:

Product Design and Development: By analyzing customer preferences and market trends, manufacturers can design products that align with consumer demands. Data correlation helps in understanding which features are most appreciated, guiding design decisions.

Production Optimization: Monitoring production data allows for the identification of bottlenecks and inefficiencies. DSS can recommend adjustments in real-time, enhancing productivity and reducing waste.

Supply Chain Management: Correlating data from suppliers, inventory levels, and delivery schedules enables proactive management of the supply chain, minimizing delays and ensuring timely fulfillment of orders.

Quality Control: Analyzing production data alongside quality inspection results can identify patterns leading to defects, allowing for early intervention and continuous improvement in product quality.

Customer Service: Integrating customer feedback with production and sales data helps in understanding customer satisfaction levels, guiding service improvements and fostering customer loyalty.

To ensure their successful implementation, it is crucial to integrate Decision Support Systems with existing company platforms, such as ERP or CRM systems. This integration ensures seamless data flow, context-aware recommendations, and operational alignment, enhancing the real-time applicability of insights and strengthening cross-departmental decision-making.

Implementing these applications requires a collaborative approach, involving cross-functional teams to ensure data is accurately collected, analyzed, and acted upon. Training staff to interpret and utilize insights from DSS is also crucial for maximizing the benefits of these technologies.

5 Machine Metrics dashboard 🔗
6 Range of key manufacturing disciplines for comprehensive, real-time data analysis.
7 Furniture warehouse.

Implementation Aspects

■ **Implementation difficulty: Medium**

Implementing AI-powered DSS and data correlation analytics requires investment in technology infrastructure and staff training. However, with scalable solutions and proper planning, medium-sized furniture manufacturers can successfully adopt these technologies to enhance their operations.

■ **Economic viability: High**

The adoption of these technologies leads to improved efficiency, reduced waste, and better alignment with customer demands, resulting in significant cost savings and increased profitability over time.

■ **Human factors**

Integrating AI-powered Decision Support Systems (DSS) and data analytics into the furniture industry triggers a fundamental shift in workforce dynamics. Employees must adapt to new technologies, which requires comprehensive upskilling efforts to foster data literacy, analytical capabilities, and confidence in digital tools. As a result, employees may experience greater job satisfaction, moving from repetitive manual work toward more strategic, high-value activities such as data interpretation and process optimisation.

Moreover, involving employees in the implementation process builds a sense of ownership, promotes buy-in, and reduces resistance. Transparent communication about the benefits and changes associated with these technologies is essential to generate trust, align expectations, and dispel uncertainty.

This transition inevitably transforms job profiles. While some positions may evolve or become obsolete, new roles in areas such as data science, AI system oversight, or predictive maintenance will open up. Companies should proactively manage this shift through targeted reskilling and upskilling strategies, fostering adaptability and preserving employee engagement and morale throughout the transition process.

■ **Environmental factors**

Implementing AI-powered DSS and data analytics contributes to environmental sustainability in the furniture industry. By optimizing production processes, companies can reduce material waste and energy consumption. Predictive analytics enable better demand forecasting, minimizing overproduction and associated resource usage. These techniques also minimize production defects, reducing rework and contributing significantly to a more sustainable and resource-efficient manufacturing process

Furthermore, these technologies support the development of sustainable products by analyzing customer preferences for eco-friendly materials and designs. They also facilitate the tracking of environmental impact across the supply chain, allowing companies to identify areas for improvement and implement greener practices.

Incorporating sustainability metrics into decision-making processes ensures that environmental considerations are integral to business strategies. This approach not only aligns with global sustainability goals but also meets the growing consumer demand for environmentally responsible products.

However, AI-powered DSS integrate large volumes of structured and unstructured data from multiple sources. These inputs are analyzed using Machine Learning algorithms which requires substantial computational power and contributes to elevated energy and water consumption and greenhouse gas (GHG) emissions.

In parallel, data correlation analytics involves comparing massive datasets to identify relationships and trends. As data volumes scale, so does the demand for processing, storage, and real-time analytics, especially when models are frequently updated or retrained. This places a growing burden on data centers. The hardware used—including GPUs, CPUs, and specialized AI accelerators—

requires rare earth elements, conflict minerals, and significant energy for production, which implies relevant environmental impact. Short product life cycles and frequent hardware upgrades contribute to electronic waste (e-waste).

■ **Alignment with certifications and regulations**

The deployment of AI-powered DSS and data analytics aligns with various industry certifications and regulations. For instance, ISO 9001 (Quality Management Systems) and ISO 14001 (Environmental Management Systems) emphasize continuous improvement and environmental responsibility, both of which are supported by these technologies. Additionally, compliance with the EU's General Data Protection Regulation (GDPR) is essential when handling customer data, ensuring privacy and data security in analytics processes.

5

6

7

Smart Decision-Making in the Furniture Sector Through Data Correlation and AI-Powered Analytics

Solutions

DataFurn
EOSC-DIH
EU ⊖

Platform-as-a-Service offering analytics for the furniture industry, enabling manufacturers to analyze online content, monitor brand influence, and forecast furniture trends.

Business Intelligence & Sales Optimization Dashboards for Furniture Companies
CPoint5
United States ⊖

Provides dynamic dashboards for furniture businesses to analyze performance, identify top-selling products, and optimize inventory and sales strategies.

Unified Data & Business Intelligence Platform for Manufacturing
Microsoft Fabric Power BI
United States ⊖

Microsoft Fabric integrates data engineering, real-time analytics, and business intelligence into a unified platform. Combined with Power BI, it enables manufacturers to visualize KPIs, apply machine learning models, and make data-driven decisions across operations, inventory, and supply chain management.

IoT-Enabled ERP for Furniture Manufacturing
Epicor
United States ⊖

Epicor's Kinetic ERP integrates IoT sensors to provide real-time insights, enabling smarter decisions, predictive maintenance, and operational efficiency in furniture manufacturing.

ERP with Supply Chain & Predictive Analytics for Furniture Manufacturing
Focus Softnet
India ⊖

Focus Softnet's ERP solution optimizes production and distribution processes in furniture manufacturing, offering robust supply chain management and predictive analytics capabilities.

AI/ML-Powered Advanced Analytics Platform for Furniture Manufacturing
SAS
United States ⊖

SAS Viya leverages AI/ML (e.g., ARIMA, gradient boosting, computer vision) for furniture manufacturing. It integrates diverse data (sensor, sales, image) for precise demand forecasting, predictive quality via anomaly detection, IoT-driven asset performance monitoring (RUL estimation), and optimized supply chains using simulation and advanced algorithms.

AI-Powered Production Planning
Ima Schelling
Germany ⊖

AI solutions for optimizing industrial furniture production, designed for large-scale manufacturers. These systems analyze data from production lines and connect it to order planning, enabling smarter decisions. Benefits include optimized nesting, reduced material waste, and improved lead times, driving greater efficiency and productivity across the entire manufacturing process.

Examples

RISE (Research Institutes of Sweden)
Sweden 🔗

Developed an AI-based image analysis tool to support furniture refurbishment decisions, enhancing circularity by quickly identifying furniture models and necessary spare parts.

Vaimo
Global
🔗

Utilizes advanced data analytics to optimize furniture retail operations, including showroom layouts, personalized customer experiences, and sustainability analytics.

Dribia
Spain
🔗

Dribia's GOIA is a custom AI-driven demand forecasting tool that combines machine learning with human expertise. It enables companies to anticipate demand fluctuations, optimize inventory levels, and reduce waste, supporting sustainable and efficient manufacturing operations.

Imperia SCM
Spain
🔗

Imperia offers a modular, AI-powered platform for supply chain planning. It enhances demand forecasting, inventory optimization, and S&OP processes, providing real-time visibility and adaptability to market changes, thereby improving operational efficiency and customer satisfaction.

Leverage AI
United States
🔗

Provides intelligent automation for supply chain management in furniture manufacturing. The platform offers real-time visibility, creates scorecards to evaluate suppliers, and automates communications, reducing buyers' time spent on order and supplier management by 50%.

Forma ideale
Serbia
🔗

Forma ideale adopted various AI technologies: generative design using GANs to create new furniture concepts based on existing data and customer preferences; AI and IoT integration to monitor equipment performance and optimize production; and smart warehouse management with autonomous vehicles to boost logistical efficiency.

Report on Industry 5.0 in EU manufacturing

This report (D2.1) presents what Industry 5.0 is, where it comes from, where it is, where it is going. The path to the new paradigm of Industry 5.0 has been long and articulated.

On this paradigm, European states are now launching programs and actions to support the 5.0 transition at different speeds to help companies and economic systems evolve and embark on that path that could lead to great development, not only economic but also human and social.

Transition 5.0 is the transition to an advanced, technology-centric industrial model, where the adoption of digital technologies such as IoT, AI, and robotics improves the efficiency, sustainability, and customization of production processes.

This change also requires a review of business practices and a greater focus on human needs. In essence, it is the step towards a highly digitized and future-oriented industry.

Industry 5.0 represents a new way of conceiving the economy and industry, a model in which technology and humanity merge harmoniously, creating a balance between efficiency and human values. It is a vision of the industry that not only aims at productivity, but also at the well-being of individuals and respect for the environment. Unlike Industry 4.0, which was configured as a real industrial and technological revolution, Industry 5.0 is above all a new cultural paradigm.

This is why it is essential to help companies, which are the real players in this new paradigm, to understand which path is best suited to their business model, starting from today's starting condition. Models and tools will be needed to understand where we start from and where we want to go, to avoid wasting resources and to make sure that we increase the competitiveness of European companies more and more.

We live in a context of continuous evolution of production systems, skills and processes, technology presents itself as a double challenge: on the one hand, it increases competitive pressure, on the other, it offers solutions to the great challenges of our time, such as the green, social and demographic transitions.

The key to dealing with these changes lies in the development of the paradigm of Society 5.0: theorized in Japan, it represents a paradigm of economic and social development that places man at the center of the synergistic relationship with technology. A step beyond the paradigm of automation typical of the 4.0 world: the goal of deploying technology in the 5.0 society is to increase individuals' well-being and quality of life, placing technology at the service of people, not as a substitute for them.

The 5.0 paradigm is essential for the future of Europe and for the success of the transitions and long-term transformative paths put in place by the European Union.

In this sense, there are two main strategic levers for a successful transition: innovation and skills, without which any technological deployment action is destined, if not to fail, not to maximize its benefits.

Report on the maturity level of Industry 5.0 in the EU furniture industry

This report (D2.2) assesses the current level of readiness of the EU furniture industry for its transition to Industry 5.0. The furniture sector demonstrates that it has the **basic knowledge for some types of technologies** that are already having an impact on production processes and that by nature and type of products have already been implemented and are therefore better known than others.

However, there are many technologies that today should be explored in depth due to the impact they can have on the life of companies that are not taken into consideration.

This is dictated by the lack of knowledge of these technologies and the lack of in-depth analysis of their potential and possible uses.

The survey outlined a **sector that is poorly informed regarding some types of technologies** and more competent on others. Overall, however, a strong lack of knowledge of these enabling technologies emerges, both for large and small companies.

This highlights the need for t**he sector to take a step forward in training** on the technologies enabling smart industry, in order to start identifying new uses and applications within a field that is still slowly moving toward the technological transformation seen in recent years.

The survey was certainly a good opportunity to understand what the most important gaps in the knowledge of these technologies are and to imagine solutions and proposals that can help companies understand the potential and tools that technology makes available today, in order to give a new innovative boost to the furniture sector.

Skills needs and recommendations for furniture sector stakeholders

In this report (D5.1), we addressed two fundamental questions: which green and digital skills are currently emerging in the European wood and furniture sector—particularly those aligned with Industry 5.0—and where do they face mismatches in demand and supply? And, how can companies in the sector effectively adopt Industry 5.0 principles by cultivating relevant skills, leveraging new technologies, and embracing European competence validation tools?

Our analysis revealed a profound transformation underway. Technical skills related to eco-design, lifecycle assessment, robotics, digital twins, and data analytics must now be complemented by transversal competences such as adaptability, systems thinking, digital collaboration, and sustainability awareness. However, supply still lags behind—digitization remains uneven among SMEs, green competencies are under-diffused, and training systems have yet to fully integrate the hybrid profiles demanded by Industry 5.0.

This mismatch has clear implications for various stakeholders: training providers need to deliver modular, flexible learning paths—microcredentials aligned with ESCO and EQF—tailored to emerging roles. Policymakers and public authorities should bolster skills ecosystems through multi-stakeholder governance, cluster-based strategies, and sectoral observatories capable of tracking skill evolution and anticipating future gaps. Enterprises themselves must shift from reactive, ad-hoc solutions toward embedding competence development directly within strategic and technological planning.

Sustained monitoring and forward-looking intelligence are essential. Skills observatories, supported by tools like Foresight Platforms and Skills Radars, will enable Europe to anticipate emerging skill needs before they become systemic constraints, ensuring both workforce adaptability and industrial competitiveness.

In sum, the central insight is that competences are the linchpin of Industry 5.0 in the wood and furniture sector. Closing the gap between emerging skill requirements and existing supply demands a dual strategy: equipping workers with hybrid green and digital capabilities while embedding these in technology adoption, business models, and collaborative networks. Competence development is not a supporting activity—it must become the driving force aligning human-centric innovation, sustainability, and digitalization with Europe's long-term industrial resilience.

Annexes

A1

Measure and strengthen your furniture company's Industry 5.0 maturity. With the Industry 5.0 Self-Assessment Tool, you will be able to evaluate your company's maturity across Technology Deployment, Sustainability, Human-Centricity and Resilience, helping furniture companies identify improvement areas and advance their transition towards Industry 5.0
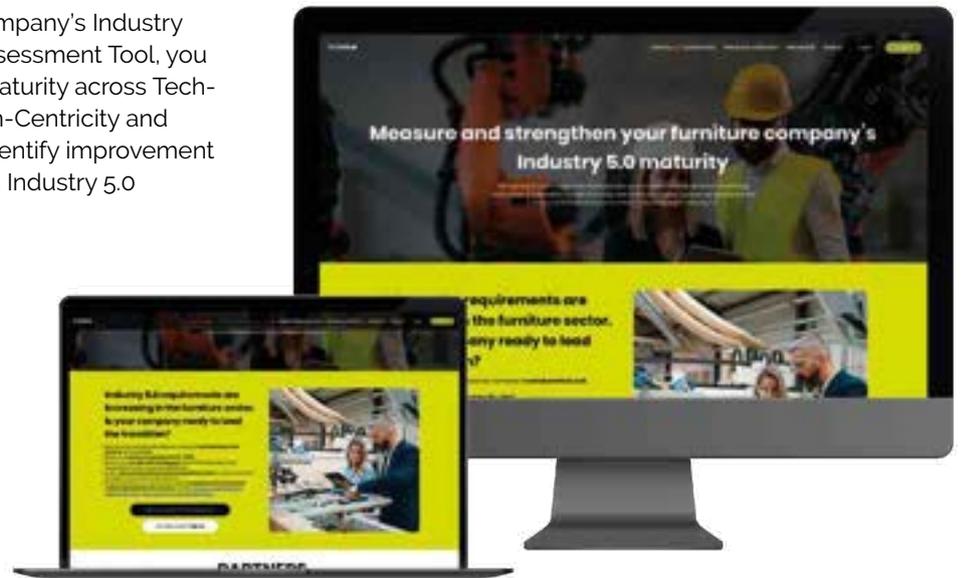
The tool in 5 steps
Follow these steps to start the self-evaluation process and take advantage of the Industry 5.0 Self-Assessment Tool's content and results

0

Sign up & Sign in
assessment.furn50.eu

1

Answer
Complete all the questions that best reflect your company's current practices and scenarios across all Industry 5.0 blocks. This will help determine your company's level of Industry 5.0 maturity and identify opportunities for improvement and the transition towards Industry 5.0

2

Assess
Review your company's Industry 5.0 maturity index and identify your strengths and maturity gaps across Technology Deployment, Sustainability, Human-Centricity, and Resilience

3

Improve
Discover how to strengthen your company's transition to Industry 5.0 by exploring recommended actions, technological applications, and selected practices that support improvement and prioritisation

4

Practices collection
Access the full collection of Industry 5.0 practices and scenarios developed within the FURN5.0 project

A2

FIX production and project union, LLC

🌐 fixunion.com.ua   UKRAINE

The self-assessment tool is clear, well-structured and straightforward to use. It provides a detailed overview of our current position and enables relevant comparisons with other countries and markets.
Most importantly, it enabled our company to develop a practical action plan and prioritise key areas for further work, especially in critical wartime areas such as circularity, resilience, and supply diversification.

Furniture plant Stryi, LLC

🌐 tivoli.com.ua   UKRAINE

The survey has clearly identified areas in which we can strengthen our development as a sustainable, future-ready manufacturing company. Based on these insights, our aim is to accelerate the deployment of targeted technologies and further enhance our sustainability practices — not only to boost our own resilience, but also to create a scalable, efficient and responsible production model within the Ukrainian furniture sector.

AQUINOS GROUP

🌐 aquinosgroup.com   PORTUGAL

The transition to Industry 5.0 poses significant challenges in addition to the ever-changing global market. Having access to practical tools, such as this one, that facilitate a smooth and efficient transition is a crucial step towards achieving this technological evolution.

Love 2 Design

🌐 love2design.org   BULGARIA

I find it to be well-developed and very helpful. I believe it provides sufficient detail to help companies understand their situation and how to improve. A comparison of results across companies could facilitate a more comprehensive understanding of the industry landscape and enable valuable international comparisons.

Svedholm
🌐 svedholm.se   SWEDEN

The tool identified various potential areas for improvement. We will focus more on applications that help us develop a more circular business model.

AZEMAD GROUP
🌐 azemad.com   PORTUGAL

It is an important tool that clearly shows which actions the company implements and which it does not, helping us to understand how we can improve in future.

ACADO
🌐 acado.bg   BULGARIA

I am very satisfied with this tool, which has provided us with a comprehensive understanding of our current status and clear guidance for our future direction. I would like to express my particular appreciation for the sections on Furniture-as-a-Service and the internal feedback tools for employee suggestions. The emphasis on supply diversification is crucial for us, and the concept of joining a resource-sharing network to enhance resilience during crises is impressive. This experience was both enlightening and inspiring as we move towards Industry 5.0.

NADOP-VÝROBA NÁBYTKU, a.s.
🌐 nadop.cz   CZECH REPUBLIC

The tool is clear and practical, providing a strong overview of our current position and key areas for improvement. It has provided valuable insights into identifying priorities in circularity, resilience, and supply diversification, offering clear guidance for transitioning towards a more sustainable, future-ready Industry 5.0 approach. The tool was easy to use and intuitive, making the overall experience efficient and user-friendly.

A2

Dřevojas, výrobní družstvo

🌐 drevojas.cz   CZECH REPUBLIC

The self-assessment tool is user-friendly, clear and visually appealing. The detailed nature of the questions posed has enabled us to gain a more comprehensive understanding and analysis of our current situation.

CitySens Lab

🌐 citysenslab.com   SPAIN

The tool has enabled us to conduct a detailed analysis of our company's current situation, identifying key processes that can be optimised and strengthened. We consider this to be a valuable opportunity for strategic growth, while remaining committed to our core purpose.

KAVE HOME

🌐 kavehome.com   SPAIN

The experience of using the tool provided a valuable learning opportunity, demonstrating the practical application of Industry 5.0 principles. The exercise proved instrumental in identifying areas for improvement and underlined the necessity for ongoing enhancement.

Waste Prevention SL (Prewaste)

🌐 prewaste.com   SPAIN

It is a highly useful tool, well-developed in technical aspects, that will undoubtedly help improve the integration of Industry 5.0 within our organisation. As a potential improvement, it would be advisable to include more practical and operational examples to better interpret maturity levels and to specify social actions more concretely, including references to policies such as supplier codes of conduct or stakeholder management guidelines.

ABSOTEC

🌐 absorcionacustica.com   SPAIN

The tool has enabled us to assess our maturity across various aspects of digitalisation, circularity and sustainability. It has also identified opportunities for improvement based on the different technologies, applications, related best practices and structured recommendations built into the tool.

NOMON

🌐 nomon.es   SPAIN

The tool has proven to be highly beneficial in providing a clear and comprehensive overview of the company's current position. It has allowed us to assess the situation from a broader perspective, identify potential opportunities, and evaluate decision-making options with greater certainty and confidence.

Tomasella

🌐 tomasella.it   ITALY

The experience was both clear and engaging, enabling us to gain a deeper understanding of how we operate and the significance of our daily decisions. The process offered concrete, structured insight into our reality, highlighting strengths and uncovering new opportunities for growth. This journey has reinforced a vision rooted in quality, consistency, and responsibility, fostering a natural evolution that enhances the present while shaping a balanced future.

Árkossy Bútor Kft

🌐 arkossy.hu   HUNGARY

The tool provided us with a range of valuable insights and clearly defined future considerations.

Plydesign Ltd.
🌐 plydesign.eu   HUNGARY

As our company continues to evolve in terms of sustainability and technology, this tool has highlighted the future directions and potential levels we can achieve.

Alples
🌐 alples.si   SLOVENIA

This is a very useful and simple tool for checking the maturity level in Industry 5.0 practices in our company, and to assess the current development and suggest a better strategic direction.

MKTECHMINDS SRL
                                                   ROMANIA

My experience with this tool has shown that integrating digital tools and fostering collaborative mindsets in education and professional development is essential. It is no longer a matter of choice if we wish to maintain our competitive edge and relevance in the constantly changing European market.

Gonzaga Pro
🌐 gonzaga.eu   SLOVENIA

Antares Romania
🌐 scaune.ro   ROMANIA

In my opinion, this is a practical and well-designed tool. It provides a concise overview of your progress in digitalisation and sustainability, and indicates your level of readiness. Additionally, it highlights several areas for improvement.

A3

This report presents the feedback collected from respondents regarding their experience with the FURN 5.0 online self-assessment tool through a specific questionnaire, which aimed to capture users' perceptions, levels of satisfaction, and suggestions for improvement after interacting with the tool. By analysing the responses, we identify strengths, challenges, and concrete opportunities for enhancing the tool's usability, relevance, and overall effectiveness.

A total of 21 respondents, company representatives from 10 European countries (Bulgaria, Czech Republic, Hungary, Italy, Portugal, Romania, Slovenia, Spain, Sweden, Ukraine), completed the survey. Overall, respondents reported a **high level of satisfaction** with the tool's usability: the graphic interface, navigation system, instructions, and readability were widely appreciated. The tool was frequently described as *smooth, friendly, and satisfactory.* Several users highlighted that the tool encouraged meaningful reflection on their company's digital and organisational maturity.

Registration and navigation were generally considered intuitive, although a few participants noted initial uncertainty at the end of the process, suggesting the introduction of a clearer final confirmation message or a progress/completion bar. Only isolated technical issues were reported.

In terms of **content**, users agreed that the questions were logically sequenced and largely aligned with their company context, though several respondents found certain items not fully applicable, especially when production is outsourced or company size is small.

Some users experienced occasional difficulty interpreting specific questions and suggested adding clearer explanations, examples, or contextual notes to support understanding.
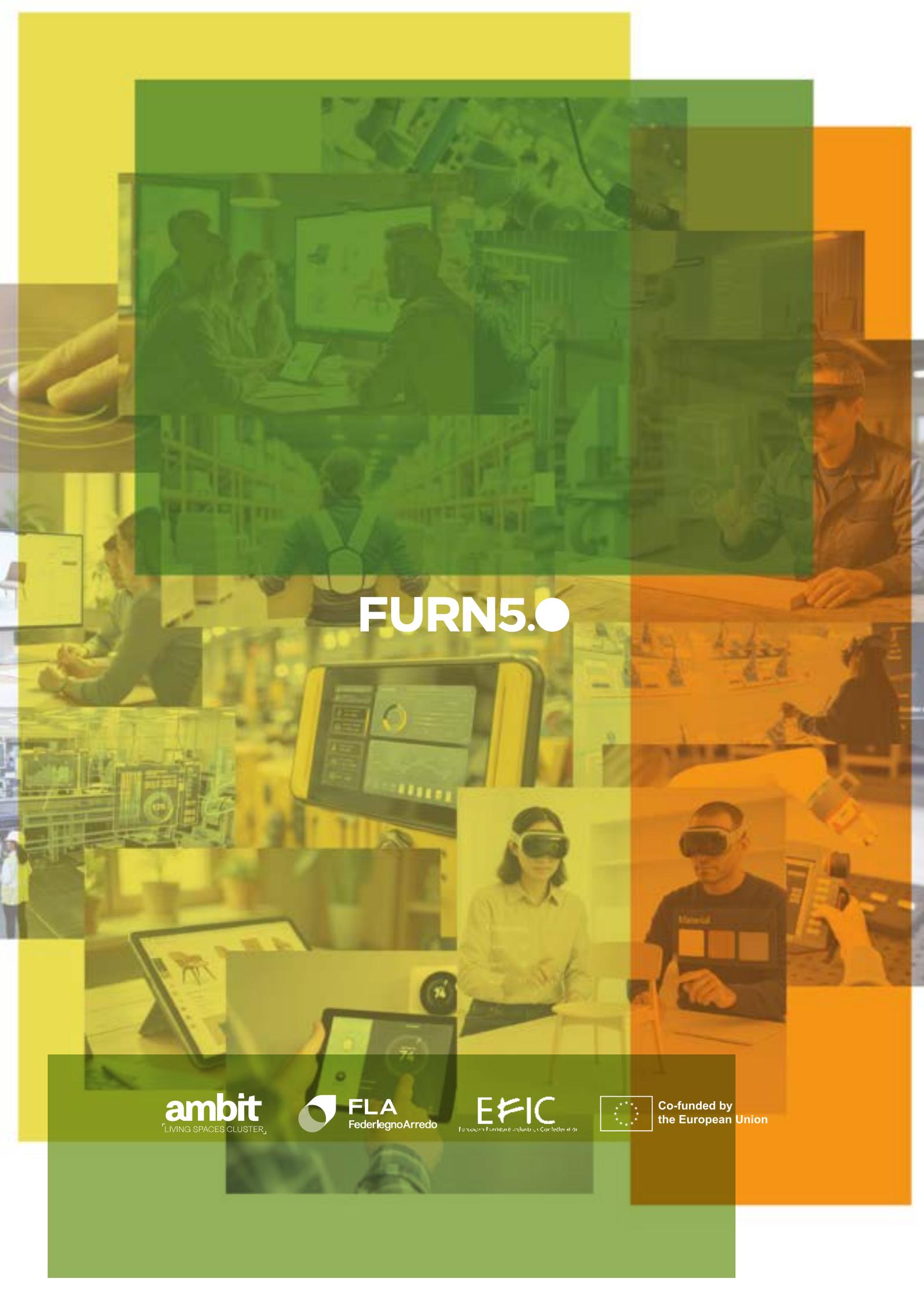
The **results section** was positively evaluated for clarity and usefulness. Respondents generally considered the outcomes realistic and relevant for supporting strategic reflection on Industry 5.0. Nevertheless, a frequent request was to enhance the tool with more detailed best-practice examples, supplier suggestions, and updated application insights.

Several users expressed interest in being able to **download a report** and to compare their performance with **European industry averages,** indicating strong demand for benchmarking features.

In conclusion, the feedback demonstrates that the FURN 5.0 tool **is widely valued for its structure, clarity, and practical relevance, effectively supporting companies in assessing their Industry 5.0 readiness**. The suggestions collected point to opportunities to further refine the user experience, expand practical insights, and enhance the tool's adaptability and strategic usefulness across diverse business profiles.

The full report is available at the following link: