INDUSTRY 4.0 CAPACITY BUILDING THROUGH DESIGN & ENGINEERING COMPETENCE. AN EXPLORATIVE STUDY ON AI INTEGRATION IN TUSCAN TEXTILE SMES

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ABSTRACT
This study investigates the role of design and engineering academics in advancing Artificial Intelligence capacity within Italy's textile manufacturing sector, particularly among Small and Medium Enterprises rooted in advanced craft-based traditions. The research centres on a collaborative workshop organised by the University of Pisa in partnership with Confindustria Toscana Nord and selected Tuscan textile companies. The aim was to introduce firms to the potential of AI in production systems by simulating its integration across the textile supply chain. Utilising the Double Diamond framework as a design thinking methodology, the workshop offered a structured, accessible model to support innovation, combining exploratory research with practical AI applications. In this context, design researchers played a pivotal role not only in simplifying technical concepts but also in contextualising AI integration strategies through creative, user-centred approaches. The initiative underscores how design researchers can act as mediators between SMEs and complex digital technologies, enabling more effective cross-sector collaboration. Moreover, the workshop's outcomes serve as a pedagogical prototype for embedding AI literacy and systems thinking into university curricula. By translating industry-relevant challenges into design-led learning experiences, academic institutions can better prepare students to contribute to digital transformation processes. This case demonstrates the potential of academia-industry collaboration to drive both technological adoption in traditional sectors and innovation in design education, fostering a new generation of professionals capable of operating at the intersection of creativity, technology, and strategy.

Keywords: AI integration, design & engineering competence, textile SMEs, capacity building, instructional design model

1 AI INTEGRATION IN ADVANCED CRAFT REALITIES: OPPORTUNITIES AND CHALLENGES FOR ITALIAN SMES
AI technology is increasingly being applied in manufacturing as companies adapt to digital production and consumption models. In digitally enabled manufacturing environments, AI contributes significantly to the optimisation of strategies and operations by facilitating stronger integration between production systems and consumer behavior analytics [1, 2, 3]. While notable strides have been made by industrial manufacturing firms toward the digitalisation of production processes [4], a distinct narrative emerges when examining advanced craft realities, particularly in the Italian context. Italy's artisanal and high-quality manufacturing sectors—such as fashion, furniture, ceramics, and luxury goods—are characterised by a deep-rooted tradition, a high degree of customisation, and regionally embedded know-how. In these settings, the integration of AI is not merely a matter of automation, but rather an opportunity to enhance creativity, preserve craftsmanship, and support intelligent decision-making in design and production.
The growing interest in the application of AI within the broader manufacturing sector is increasingly driven by a bottom-up approach. This phenomenon is notably present in Italy's craft-based districts, where small and medium-sized enterprises (SMEs) are experimenting with AI tools in product design,

prototyping, and customer personalisation. These integrations are often facilitated through AI-powered platforms that support trend prediction, consumer profiling, and even virtual try-on technologies. In particular, web-based service design and digital marketing platforms have seen widespread adoption of AI for forecasting and campaign optimisation, empowering craft enterprises to align their production with market demand and consumer preferences [5, 6].

Nonetheless, the integration of AI into the product development lifecycle across Italian manufacturing districts remains uneven and fragmented. Structural disparities persist between regions and sectors in terms of access to digital infrastructure, technical expertise, and financial resources. According to the EU SME Annual Report 2021 [7], many SMEs continue to face significant barriers to adopting advanced technologies, which are further compounded in traditional manufacturing clusters. In Italy, where production ecosystems are often organised around supply chains and territorial networks, innovation is rarely driven by a single actor. Instead, it emerges from collaborative efforts, often involving design studios, artisans, research centres, and local institutions.

This complexity underscores the need for a systemic innovation model tailored to the unique characteristics of Italy's advanced craft realities. Such a model would emphasise co-creation, shared digital platforms, and cross-sector alliances to facilitate AI adoption. A coordinated framework—engaging SMEs, industry leaders, public institutions, and academic bodies—would help bridge the digital divide and promote an inclusive technological transformation, ensuring that the integration of AI supports both economic competitiveness and the cultural distinctiveness of Italy's manufacturing heritage [8, 9, 10].

2 THE INTERVENTION OF DESIGN INSTITUTIONS IN ITALIAN INDUSTRIAL DISTRICTS

At the intersection of academia and industry, collaborative workshops between design students and companies have become a well-established practice aimed at generating innovative concepts for new product-service development. These initiatives, grounded in design thinking methodologies, offer valuable opportunities for students to contribute fresh insights and exploratory directions, particularly in sectors where customisation and user-centred innovation are central [11, 12]. In Italy, such collaborations have taken shape through initiatives like the Art, Design and Enterprise for New Young Talents project in Tuscany and the Upskill 4.0 program, where design and technical students are embedded in local SMEs to co-develop innovative solutions and enhance strategic capabilities [13]. Additionally, the Politecnico di Milano's Project-Based Learning (PBL) model has enabled students to engage directly with companies in addressing real-world challenges, strengthening both the educational and innovation impact of such partnerships [14, 15].

However, when attention shifts from concrete product-service systems to broader strategic innovation—such as reimagining business models, cultural value propositions, or sustainability frameworks—the contribution of academia evolves to become more structured and research-oriented. In this domain, design researchers play a critical role in shaping strategic trajectories, as highlighted by the work of Deserti and Rizzo [16], and Celaschi et al. [17], who frame design as a medium for transformation and envisioning future scenarios within complex socio-technical systems. Design-led research enables companies, particularly SMEs in traditional sectors, to engage in future-oriented thinking and innovation beyond incremental change [18].

Despite these promising developments, a significant gap remains in the integration of AI within design-led academic-industry collaborations—especially in contexts involving advanced craft realities. While AI offers powerful tools for enhancing decision-making, personalisation, material innovation, and trend forecasting, its presence in design education and research initiatives addressing strategic innovation remains fragmented. This disconnect is especially apparent in advanced manufacturing and craft-based industries, where the integration of AI could support more responsive and customised production processes without compromising artisanal identity [19, 20]. The lack of digital literacy and AI fluency within many design programs limits the ability of future designers to act as effective mediators in digitally augmented innovation ecosystems. Addressing this educational gap is critical to ensuring that emerging professionals can engage with the data-driven, platform-based models increasingly shaping the future of design and production.

3 METHODOLOGIES

This research explores the strategic role of AI capacity building in the advanced craft realities of the textile manufacturing sector in Tuscany, Italy. In this context, design researchers emerge as pivotal actors in facilitating digital transformation, particularly within SMEs operating in traditional industrial districts. The study investigates how academic collaboration—specifically between design and engineering faculties—can catalyse the adoption of AI technologies in production processes that are historically rooted in artisanal expertise and low levels of digitalisation. Central to this investigation is a workshop organised by the University of Pisa in collaboration with Confindustria Toscana Nord and a curated selection of Tuscan textile SMEs.

The workshop was designed as a capacity-building initiative, aimed at exposing SMEs to the potential of AI through tangible, accessible, and context-sensitive methodologies. Drawing from the Double Diamond framework [21], the research team introduced a design-driven model that combined strategic foresight, creative exploration, and data-supported decision-making. By incorporating design thinking principles, researchers offered companies a structured yet flexible approach to exploring how AI could be integrated into their production systems—not as a disruptive imposition, but as an enabler of process innovation, customisation, and strategic foresight.

Design researchers contributed decisively by translating the abstract potential of AI into actionable formats through simplified tools, scenario-based simulations, and cross-disciplinary references. Their mediation bridged the gap between technical AI capabilities and the tacit knowledge embedded in local craft systems, supporting companies in articulating their needs, mapping existing digital assets, and envisioning possible AI applications. This facilitative role is especially critical in Italian manufacturing districts, where innovation often emerges from distributed knowledge systems and informal networks, rather than from centralised R&D departments.

Moreover, the workshop highlighted the importance of interdisciplinary academic knowledge in overcoming barriers to AI adoption—such as lack of technical literacy, resource constraints, and organisational inertia. By acting as both cultural translators and strategic facilitators, design and engineering academics helped SMEs navigate the complexities of AI integration, aligning technological innovation with existing values, production cultures, and market orientations. This approach not only empowered participants to envision AI-enhanced futures but also laid the groundwork for sustainable innovation ecosystems rooted in both digital intelligence and local identity.

3.1 The manufacturing district of Prato

The investigation referred to companies that participate in the district of Prato as the context of inquiry. The district of Prato represents the most significant textile-fashion hub in Europe and exemplifies the industrial district model—a distinctive organisational structure characterised by a high degree of labour division and specialisation among small enterprises. In this system, competitiveness is driven more by territorial external economies than by internal economies at the individual firm level [22]. Prato's textile enterprises, key players in the global fashion value chain, have long collaborated with major international apparel brands [23].

Particularly, the district is characterised by small enterprises with highly specialised competencies. However, in light of emerging business models, these firms face significant challenges in embracing the Industry 4.0 revolution. The ongoing digitalisation of production processes necessitates further transformation to sustain and enhance the district's global competitiveness. The Prato textile-fashion sector must innovate its production processes to improve efficiency, cost-effectiveness, and responsiveness to market demands. Textile enterprises require advanced capabilities in logistics, traceability, monitoring, and quality control, which can only be achieved through the adoption of emerging technologies supported by modern ICT and advanced engineering networks.

Currently, nearly 50% of Italian Industry 4.0 firms rely exclusively on data-related technologies, such as horizontal and vertical information integration, cloud computing, big data, and analytics. Additionally, over one-third of these firms have adopted advanced production technologies, including interconnected robotics, additive manufacturing, simulations, augmented reality, and smart materials. In Tuscany, the majority of firms (38.5%) integrate both data and production technologies, though the adoption rate of big data analytics (0.4%) remains lower than the national average (1.3%) [24].

4 THE DESIGN SUPPORT SYSTEM (DSS) MODEL: INTEGRATING AI IN THE DESIGN THINKING MODEL

The workshop's development of the Design Support System (DSS) model) Fig.1) exemplifies a sophisticated integration of design thinking principles with advanced digital tools, particularly AI, to strategically support innovation in manufacturing and craft-based enterprises. Rooted in the Double Diamond framework popularised by the UK Design Council [21], the DSS operationalises design thinking as a cyclical and iterative process that alternates between divergent and convergent phases of problem exploration and solution definition. This process is vital to navigating complexity in product-service systems and advanced manufacturing environments [11, 25].

In the divergent "Discover" phase, the DSS system facilitates a holistic, user-centred inquiry that is essential to design thinking's emphasis on empathy and contextual understanding [26]. The system harnesses thematic tools such as case-based reasoning and multi-dimensional data collection—spanning vertical (sector-specific) and horizontal (cross-sectoral) analyses—to broaden the perspective beyond traditional industry boundaries. This aligns with recent scholarship emphasising design thinking as a transdisciplinary approach that encourages knowledge transfer and co-creation across different domains, fostering innovation through analogical reasoning and expansive inquiry [27].

The use of AI in this phase is particularly innovative: by integrating real-time data analytics and pattern recognition, the DSS augments human insight with computational rigor, addressing the common challenge in SMEs of limited resources for extensive market or trend research. AI supports the "discovery" process by filtering vast amounts of heterogeneous data—ranging from market trends to social sentiment analysis—thereby facilitating a richer, evidence-based understanding of the context. This application reflects an emerging discourse on the convergence of design thinking and data science, which argues that AI can enhance the creativity and problem-framing stages without supplanting the intuitive and empathetic core of design practice [28, 29].

In the subsequent convergent "Define" phase, the DSS operationalises the narrowing of focus to synthesise insights into actionable design strategies, mirroring design thinking's iterative refinement of ideas [11]. The creation and dynamic evolution of strategic moodboards provide a visual and tangible medium through which designers, entrepreneurs, and other stakeholders can co-validate and co-create solutions. The moodboard acts as an interface between machine-generated analytical outputs and human creativity, enabling iterative feedback loops that embody the human-centred ethos of design thinking. This cyclical iteration enhances transparency and inclusiveness in decision-making, fostering trust and shared ownership of innovation trajectories [30].

Moreover, the DSS's emphasis on codifying production taxonomies through "discrete" digitalisation and its bridging of automated and craft-based processes exemplify the evolving scope of design thinking beyond mere product design to encompass systemic and organisational innovation [31]. The "dialectical" relationship between design thinking's structured phases and AI-supported taxonomy management underscores the potential for design thinking to evolve in tandem with Industry 4.0 paradigms, wherein human-machine collaboration drives resilient, adaptive, and customised production ecosystems [32, 33].

In summary, the DSS model presented in the workshop illustrates how design thinking can be enriched by AI and data-driven methodologies without losing its fundamental human-centric and iterative nature. It highlights the potential for design strategies to be grounded in rigorous data analysis while remaining flexible and sensitive to the tacit knowledge and creative insights that designers and entrepreneurs bring to the innovation process. This hybrid approach addresses contemporary challenges faced by advanced craft realities in Italy and elsewhere, positioning design thinking as a pivotal enabler of digitally augmented, yet authentically human, innovation.

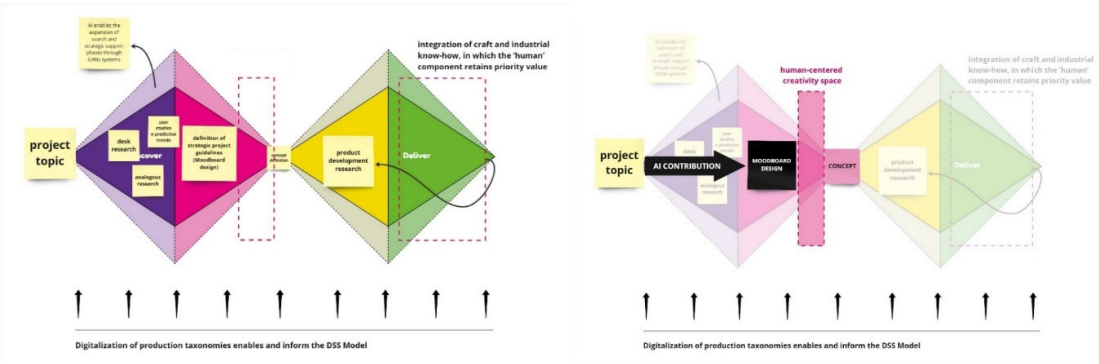

Figure 1. A schematisation of the DSS Model with a focus on AI e Human-based design integration through the interactive moodboard design tool

5 CONCLUSIONS

The integration of AI as a driver of industrial transformation presents both a strategic opportunity and a pedagogical challenge, particularly for design education. The workshop analysed in this research—developed and conducted by design researchers in collaboration with companies—served as a critical experiment in fostering innovation across the boundaries of academia and industry. Focused on textile SMEs in Tuscany, the initiative aimed to expose enterprises to the transformative potential of AI while providing a structured, accessible model for integrating data-driven approaches into traditional production systems. At the core of the workshop methodology was the application of design thinking, which has emerged as a shared language capable of mediating between distinct disciplinary domains such as strategic design, computer science, and manufacturing. By grounding the process in the Double Diamond framework, the workshop allowed design researchers to guide companies through exploratory and strategic phases that reimagined their production processes and decision-making practices. The iterative and user-centred nature of design thinking not only facilitated cross-sector dialogue but also enabled firms to envision AI not as a disruptive imposition, but as a collaborative and contextualised tool for innovation. While students were not direct participants in this phase, they represent the next generation of adopters of the workshop model. As the framework developed through this academic-industry collaboration becomes embedded in teaching practices, it offers a powerful pedagogical tool for equipping students with the skills needed to work across disciplinary boundaries and engage meaningfully with AI in professional contexts. By integrating insights from the workshop into design education, students are introduced to real-world methodologies that blend creative exploration with digital capability-building—especially within the nuanced environments of craft-based production.

The workshop also affirmed the evolving role of design researchers as facilitators of digital transformation in SMEs, particularly in regions characterised by complex manufacturing districts like those in Tuscany. Researchers acted as translators between technical potential and operational relevance, enabling AI to be understood and applied in ways that respected local production logics and cultural identity. This bridging function is essential in contexts where SMEs may lack the internal capacity to experiment with emerging technologies independently.

In this context, design education is not merely reacting to digital transformation—it is increasingly enabling it. Through models developed by design researchers and transferred to students, academic institutions are helping to cultivate a new generation of professionals equipped to navigate and lead within the rapidly evolving terrain of AI-enhanced production.

REFERENCES

[1] Chui M., Manyika J. and Miremadi M. (2018). Artificial Intelligence: The Next Digital Frontier? McKinsey & Company.

[2] Brynjolfsson E. and McAfee A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. W. W. Norton & Company.

[3] Davenport T. H. and Ronanki R. (2018). *Artificial Intelligence for the Real World.* Harvard Business Review.

[4] Re N. U., Ghezzi A., Balocco R. and Rangone A. (2023). Understanding SMEs digitalisation: a literature review of maturity models.

[5] Chung S. and Lee J. (2019). Artificial Intelligence and Marketing: Past, Present, and Future. *Journal of Business Research*, 98, 280-287
[6] Kumar V. and Shah D. (2020). Artificial Intelligence in Marketing: Theories and Applications. *Marketing Science*, 39(5), 819-838.
[7] European Commission (2021). *SME Annual Report 2021*. European Union.
[8] Müller J. M., Kiel D. and Voigt K.-I. (2023). Artificial intelligence adoption and revenue growth in European SMEs: The impact of AI, IoT, and big data analytics. *Industrial Management & Data Systems*, 123(3), 567-586.
[9] Meroni A. (2024). Intelligenza Artificiale e PMI: sfide e opportunità di adozione. Skilla Blog.
[10] Srinivasan V. and Kurey B. (2023). Driving SME innovation with AI solutions: overcoming adoption barriers and exploring growth opportunities. *International Journal of Small and Medium Enterprises and Business Sustainability*, 1(1), 45-60.
[11] Brown T. (2009). *Change by Design: How Design Thinking Creates New Alternatives for Business and Society*. Harvard Business Press.
[12] Meinel C. and Leifer L. (2011). *Design Thinking: Understand–Improve–Apply*. Springer.
[13] Upskill 4.0. (2023). *Progetti di Innovazione con ITS e PMI*. Retrieved from https://upskill40.it
[14] Manzini E. and Coad R. (2015). *Design, When Everybody Designs: An Introduction to Design for Social Innovation*. MIT Press.
[15] Bertola P. and Teixeira C. (2021). *Design Futures Literacy: Design as a Capability for Transition*. She Ji: The Journal of Design, Economics, and Innovation, 7(1), 30–47.
[16] Deserti A. and Rizzo F. (2014). *Design and the Cultures of Enterprises*. Design Issues, 30(1), 36–45.
[17] Celaschi F., Celi M. and García M. (2012). *The Extended Value of Design: An Advanced Design Perspective*. Design Management Journal, 7(1), 6–15.
[18] Zurlo F. (2019). *Strategic Design: From Design Thinking to Design Strategy*. FrancoAngeli.
[19] Micelli S. (2011). *Futuro Artigiano: L'innovazione nelle mani degli italiani*. Marsilio.
[20] Bianchini M., Maffei S. and Parisi S. (2021). *Design for Distributed Economies: Towards a New Framework*. Strategic Design Research Journal, 14(1), 47–59.
[21] British Council (2005). The Double Diamond. A Universally Accepted Depiction of The Design Process. *https://www.designcouncil.org.uk/our-resources/the-double-diamond/*
[22] Confindustria Prato (2024). Distretto Pratese. Breve sintesi della sua evoluzione. http://www.ui.prato.it/unionedigitale/v2/areastudi/Presentazione-distretto.pdf.
[23] Municipality of Prato and Next Technology Tecnotessile (2024). Smarty Action-Plan. Interreg Europe.
[24] European Union (2020), Smarty-Interreg Europe, within Smart SMEs for Industry 4.0. https://www.cittadiprato.it/IT/Sezioni/617/SMARTY-INTERREG-EUROPE/.
[25] Liedtka J. (2018). Why Design Thinking Works. *Harvard Business Review*, 96(5), 72–79.
[26] IDEO (2015). The Field Guide to Human-Centered Design. IDEO.org.
[27] Carlgren L., Elmquist M. and Rauth I. (2016). Design thinking: Exploring values and effects from an innovation capability perspective. *R&D Management*, 46(3), 300–311.
[28] Davenport T., Guha A., Grewal D. and Bressgott T. (2020). How artificial intelligence will change the future of marketing. *Journal of the Academy of Marketing Science*, 48, 24–42.
[29] Dorst K. and Cross N. (2001). Creativity in the design process: Co-evolution of problem–solution. *Design Studies*, 22(5), 425–437.
[30] Norman D. A. (2013). The Design of Everyday Things. Basic Books.
[31] Manzini E. (2015). Design, When Everybody Designs: An Introduction to Design for Social Innovation. MIT Press.
[32] Bucolo S. et al. (2018). Design thinking in Industry 4.0: from product to system innovation. *Design Studies*, 57, 53–73.
[33] Micelli S. (2021). Crafting the Future: Design and Digital Innovation in Italian Artisanship. Springer.