Fashion craftsmanship 4.0: learning experience about Industry 4.0 technologies for hybrid digital fashion-tech products, processes, and business model design

Daria Casciani[1], Olga Chkanikova[2]

[1]Politecnico di Milano – Department of Design, Italy
daria.casciani@polimi.it
[2]Department of Business Administration and Textile Management, University of Borås, Sweden
olga.chkanikova@hb.se

Abstract
The European fashion craftsmanship sector is renowned worldwide for its excellence and competitive value in producing tangible and intangible cultural heritage (ICH) in creative practices and material artifacts. However, the competition of mass production at lower costs and the increasing jobs digitalization threatens the survival of fashion craftsmanship knowledge. In this context, Industry 4.0 (I4.0) technologies could become a trigger to transform fashion craftsmanship by hybridizing workflows via new tools, gestures, and creative acts. Due to a technological and socio-cultural divide between the old and future generations of fashion craftspeople, new educational models are necessary to update the skills and imagination of future fashion professionals towards the revival of crafts ICH while accounting for holistic multidimensional sustainability. Therefore, the paper presents an interdisciplinary challenge-based learning experience conducted at Politecnico di Milano and University of Borås, combining a design and business management methodological approach to deliver Fashion-Tech proofs of concepts (covering product, service, process, and business model innovations). Delivered proofs of concepts demonstrate the potential of I4.0 technologies to preserve cultural diversity and local heritage, improve multiple dimensions of sustainability, and empower creativity and connectivity between different stakeholders. New products, services, processes, and business ecosystems of hybrid fashion craftsmanship can contribute to interdisciplinary learning spaces where different users/stakeholders connect and engage in co-creation and co-learning activities. Besides, the developed educational model can be applied to training fashion craftspeople 4.0.

Author keywords
digital design; digital fabrication; fashion craftsmanship 4.0; education for Fashion-Tech; sustainability.

Introduction
The technological and socio-cultural divide between old and future fashion craftspeople is nowadays impacting the lack of generational turnover and the preservation of intangible cultural heritage (ICH) in the Italian and European fashion craft sectors. The meaningful application of Industry 4.0 (I4.0) technologies via new educational models could bridge this gap by enabling digital literacy, the connection of stakeholders, and the pursuit of environmental, political, cultural, and socio-economic sustainability. The paper presents the results of an interdisciplinary learning experience and discusses the implications of training future professionals in the hybrid (i.e., analogue/digital) fashion craftsmanship sector, focusing on creativity and collaboration.

Literature review

Traditional and future fashion craftsmanship at risk of extinction
The European fashion craftsmanship sector is recognized for its quality, creativity, and competitive economic value in producing cultural content embedded into creative practices and material products. European (e.g., Italy, France, Germany, Spain, Portugal) fashion micro-enterprises of craft-based high-end personal goods (e.g., textile and clothing, jewellery, eyewear, and leather goods accessories) represent 74% of the global value of these products (EC, 2023a). In particular, the EU textile and clothing craft sector employs 1.5 million people and produces a turnover of €147 billion (Euratex, 2022); meanwhile, about 36K enterprises generating a turnover of €48 billion and employing around 435K people produce leather crafts (EC, 2023c). Fashion craftspeople inherit and preserve the knowledge, expertise, and skills of crafting unique and excellent artefacts as Intangible Cultural Heritage (ICH), being custodians of traditional expertise situated in specific territories and communities (UNESCO, 2003). However, the competition of global mass production at lower costs, the delocalization of manufacturing to places with cheaper hand labour, and the spreading digitalization are forecasted to cause a shortage of traditional fashion and textile artisanal experts across the operational, technical, managerial, creative and scientific sectors (ETP, 2016). Passing the tacit artisanal knowledge through the familiar entourage and on-the-job learning practices inside workshops further

reduces the number of available expert craftspeople in the fashion sector. For example, in 2013, Confartigianato Imprese predicted an unexpected death of Italian craft entrepreneurs, specifically in the sector of design, fashion, and personal luxury items (e.g., leather, footwear, clothing, and jewellery), thus impacting the decrease of 'Made in Italy' economy by 9.1% (Bonfanti et al., 2015). Since the fashion craftsmanship sector is a significant asset for economic, cultural, social, and environmental sustainability, the European Commission primarily focuses on revitalizing European urban and rural areas by nearshoring the craftsmanship processes toward a feasible and resilient governance of a post-emergency society (EC, 2023b).

Exploiting digital technologies toward fashion craftsmanship 4.0

To stay competitive against mass globalization and production, small and local artisanal enterprises could exploit I4.0 technologies to develop highly customized products through on-demand production at fair and competitive prices on the market, while increasing product uniqueness and quality. In addition, they can become a trigger for encouraging new generations of artisans' to produce new crafts through new workflows aided by I4.0 technologies, thus hybridizing traditional practices towards a systemic paradigm change in the fashion ecosystem (McCullough, 2015; Bertola and Teunisen, 2018). I4.0 technologies could also help digitize traditional fashion crafts gestures and processes, translating the intangible fashion knowledge into teaching materials to incentivize mutual learning between humans and technologies, thus nurturing the future generation of fashion professionals in old craft sectors (Casciani and Vandi, 2022). Besides, studies demonstrate that I4.0 technologies define new relationships between artisans and technologies, particularly in assisting or augmenting daily manufacturing tasks toward operators' health, well-being, and safety (Burden, Donovan, Caldwell, Teixeira, 2022). However, the digital transformation in Italian fashion crafts enterprises is still far from a mature reach, with 9.5% in the eyewear sector, 5.8% in jewellery, 14.2% in the clothing and apparel sector, 8.4% in textile, 1.6% in footwear (Digital Manufacturing Lab, 2018). The main constraints for this limited adoption from Italian and European fashion crafts enterprises are the inadequate knowledge about I4.0 technologies' opportunities which is related to a different business strategy and culture of the enterprise, the lack of internal/external competences, constrained financial resources, and the difficulty in identifying the right partner to drive the digital transition (Digital Manufacturing Lab, 2018; Kusters et al., 2017). Adopting I4.0 technologies represents a complex challenge for the present craftspeople with limited digital skills across engineering, design, and business management domains (Jimeno-Morenilla et al., 2021). The advantages of embracing digital technologies in fashion craft-based workflows rely on boosting products' quality and exclusivity, improving working conditions, increasing productivity and efficiency, and reaching sustainability. From a cultural perspective, digital technologies could help revive the crafts communities and maintain cultural diversity and local identity (Brown and Vacca, 2022). Despite this, craftspeople face sociocultural barriers toward I4.0 technologies in terms of expectations, reluctance to use, perceived lower quality of implemented crafting processes, and fear of the complete automation of work towards the disappearance of artisanal practices and job loss (Mosca and La Rosa, 2019).

Training future fashion hybrid craftspeople

The shortage of craftspeople and associated skills and knowledge in the fashion sector is expected by 2030 (ETP 2022) due to a huge turnover of employees after the retirement of highly specialized artisans. Besides, fashion craftspeople face the challenge of adapting their workflows to respond to the green and digital economy transition, with the conflicting demand of focusing on retaining existing competencies, and attracting new talents (ETP, 2022). Hand-based craftsmanship has lost its attractiveness and safety with a consequent decrease in interest by a younger generation of professionals. However, research has forecasted a future scenario of fashion industries in 2030 focused on the Renaissance of the Crafts regarding production, employment, required skills, and competences (Skills 4 Smart TCLF Industries 2030, 2022).

The intergenerational technological and socio-cultural gap between old and new fashion craftspeople should be mitigated to preserve and transmit the fashion craftsmanship ICH through digital literacy provision to the older generation of artisans, meanwhile incentivizing the interest of the younger generation to hand-based craftsmanship hybridized with the use of I4.0 technologies. New educational models aim to achieve the aforementioned objective and to drive the digital transformation and sustainability of the European fashion eco-system, preserving both specialised traditional skills while advancing the new ones relevant to the digital evolution of the sector (Bertola and Vandi, 2021; Digital Education Action Plan (2021-2027), 2021; Unesco, 2017). Besides, new educational models should also foster the encounter of traditional and future craftspeople, supporting collaboration and peer-to-peer learning and education. In this direction, a series of piloted learning experiences (LE) have already suggested that innovative proof of concepts of sustainable Fashion-Tech solutions could be enhanced by the use of a challenge-based learning (CBL) approach, by combining design and business model perspectives (Casciani et. al, 2020; Casciani and Colombi, 2022; Ma, 2022;). In the CBL approach, students face real-life and multidimensional problems involving social, cultural, economic, technological, and environmental dimensions and are encouraged to formulate their solution by collaborating with different stakeholders involved/affected by the process or solution, thus allowing the connection between students, teaching staff, professionals, technologists, researchers, and artisans (Nichols and Cator, 2009; Nichols et al. 2016). Due to the complexity of the real-world challenges, the CBL approach supports the connection of knowledge among different disciplines, resulting in sharing common glossaries, and perspectives toward the synergistic integration and modification of disciplinary contributions. Hence, education is crucial to maintain, and valorise fashion craftsmanship ICH by cultivating and nurturing future fashion professionals that combine digital skills while preserving the traditional material and manufacturing competences.

Methodology

The paper presents an international and interdisciplinary LE conducted by Politecnico di Milano and University of Borås collaborating to train the hybrid fashion professionals of the future with soft skills, technical/digital, and subject-specific skills while boosting integration between the human, so-

cio-cultural, and economic perspectives. The LE focused on the implementation of the more operative I4.0 technologies such as 3D printing (3DP), 3D scanning (3DS), laser cutting (LC), collaborative robotics (CR), virtual and augmented reality (VR/AR) in the design of new craft products/systems of products, new hybrid digital crafting processes, and new business models that also account for a multidimensional perspective of sustainability. By coupling design-driven and business management innovation perspectives inside an interdisciplinary action-oriented pedagogical approach, we aimed to encourage a positive and culturally meaningful paradigmatic shift, bringing students closer to crafts and craftspeople and preserving and enhancing traditional practices through digital transformation. The combination of design and business model innovation education is crucial to support the possibility of achieving a real and fruitful digital transition in the fashion craftsmanship sector (Jin & Shin, 2021). Focusing on the comparison between pre- and post-course skills self-assessments, derived from the answers from the questionnaire and by the analysis of the LE results such as proof of concepts and group project reports, the paper aims to discuss the impact of the piloted educational models for the fashion crafts' digital transformation towards sustainability. In particular, this study intends sustainability as a holistic multidimensional concept entailing environmental, economic, social, and cultural dimensions (Fletcher, 2014; UCLG, 2010; British Council, 2020).

LE design: developing collaboration, toolkit, and educational methodology

Growing interdisciplinary Fashion-Tech partnerships

The LE has been offered to 21 international and interdisciplinary students (76% female, 19% male, 5% non-binary gender) from graphic design (5%), product design (21%), fashion design (52%), architecture and landscape (10.5%), and business management (10.5%). They worked in 5 interdisciplinary groups mentored by 2 academic researchers/teaching staff from the involved Universities and 2 professional tutors from a Fashion-Tech start-up focusing on digital transformation, and non-standard fabrication technologies (Materea). The company participated actively in the LE design, delivered technology-focused lectures as expert trainers, and mentored students during the CBL phase. Students were asked to select one between five different applications of the fashion craftsmanship sectors (jewellery, textile and clothing, small and medium accessories in leather, footwear, and eyewear) since these sectors are at the forefront of Italian fashion craftsmanship (Bonfanti et al. 2015). Students were expected to focus on specific historical craftsmanship expertise and techniques with no geographical boundaries. However, being asked to include the craftspeople of the selected applications in the research and design processes, many focused on the Italian geographical context because most students were based in Italy. However, the LE allowed for a broader geographical scope/context to account for international students' interests and competences. In particular, some students focused on fashion craftsmanship in the Far East and Asia. Students have developed solutions such as low-fidelity prototypes, visualizations of workflows, and mock-ups of designed solutions, tools, and software. These outputs were shown to the stakeholders to test and provide a reality-check of the proposed proofs of concepts (PoC). Craftspeople were surveyed (7) and interviewed/observed (11) during their activities and were confronted with the hybridized crafted processes. Targeted final consumers were interviewed (12) and surveyed (78) to define needs and feedback in relation to the proposed hybridized crafted solutions.

Setting connected learning workspaces

The LE was delivered through 13 digital lectures divided into an initial theoretical part (DISCOVER), providing basic knowledge on design, methodology, engineering, and business management topics, and followed by a CBL part (DESIGN). It was aided by a system of educational tools providing an individual personalised learning path, such as Fashion-Tech Open Educational Resources (OER, 2022), and digital collaborative visual boards structured on MIRO to aid the communication, interdisciplinary exchange, collaboration on design activities and project management, toward a sharing of disciplinary glossary and methodologies, and asynchronous and synchronous interactions. OERs were focused on levelling the knowledge for students of different backgrounds to easily drive the CBL. Collaborative visual spaces were useful to both set up the activities, control the progress through the course timeline, and set a fruitful partnership between the instructors and learners as co-researchers/designers of the solutions during mentoring activities.

Joining design and business-driven innovation methods toward sustainability

To conduct a digital LE, a user-centred design approach combined with principles of design for sustainability/circularity and sustainable/circular business model (BM) innovation perspective was decided (Fig.1). User research aimed to understand craftspeople workflow, activities, tools, materials, needs, and challenges in integrating I4.0 technologies. This was complemented with final customer research to delimit main market segments for hybrid fashion craft. In addition, students focused on sustainability strategy, starting from the project groups' vision, mission, and core sustainability values formulation and then connecting it to specific Sustainable Development Goals (SDGs). Subsequently, the hybrid systems of product, process, and business model concept ideas were conceived, integrating research of available digital technologies adaptable in the fashion craft sector. Simultaneously running the product, process, and business model conceptualization stages aimed to facilitate the systemic interdisciplinary approach toward sustainability within the project teams. According to students' reports and evaluations, this allowed for a number of iterations and simultaneous adjustments of ideas that were detailed and visualized with low-fidelity mock-ups to be tested and validated with users (artisans + customers), thus providing a further design iteration (Fig.1).

LE results: hybridizing fashion craftsmanship practice through education

Hybridizing crafts system of products, processes, services, and business models

Implementing I4.0 technologies in students' solutions of hybrid systems of products, services, processes, and business models influenced the redefinition of fashion design, production,

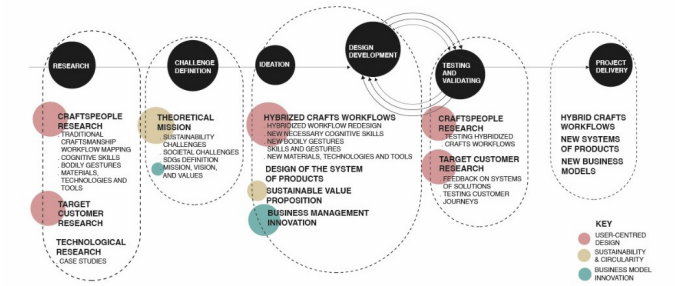

Figure 1. LE workflow from research to project delivery, blending design, and BM education

and consumption logic by challenging existing unsustainable models while attempting to preserve fashion craft ICH (Fig.2).

Students have developed 5 proof of concepts (PoCs) focusing on purely hand-based craft sectors (e.g., jacquard crocheting, stringing beads, hat weaving) and hybrid sectors already using technologies in some parts of the manufacturing processes (e.g., eyeglasses and dress shoemaking). In the latter, they focused on niche artisanal products, still very traditional and based on manual workflows.

PoC1 aims to preserve the jacquard crochet legacy by customizing the design of bags and small accessories, empowering international artisans with digital technologies to parametrize the design phases and augmented tools with sensors that amplify and extend their gestures. An online configurator allows product customization, and direct connection between artisans and customers, aiming to promote awareness of the crafts' tradition amongst the general public. PoC2 develops personalized advanced modular and long-lasting Italian dress shoes, augmenting traditional workflows of perfect fit and personalization with 3D scanning and Virtual Reality (VR) try-on technologies on a digital online configurator. The repetitive and cyclical activities of material cutting are aided through 3D printing and laser cutting, while the assembly is through collaborative robots. PoC3 develops 3D-printed interlocking beads made from recycled filaments, improving the efficiency and operability of international craftspeople during the beads stringing process, while allowing beads customization via simplified parametric digital configurator and VR try-on. PoC4 focuses on customized headwear weaving, combining the precision and speed of laser cutting with the uniqueness of traditional Vietnamese crafts techniques, thus promoting local economic development and customer personalization via head scanning and an online configurator. PoC5 creates a digital platform to connect a network of artisans able to offer sustainable and fully traceable glasses made of recyclable materials, thus offering a service of disassembly, repair and renovation throughout Italy, to extend the life cycle of glasses while allowing a customized artisanal work through face scanning, digital design, and fabrication.

Similar solutions are already present in the activities of researchers and design practitioners working on creative experimentation and co-creative practices, investigating the interaction between humans and robots (Ugur, 2020; Performative robotic micro-factories, 2021), humans and digital fabrication (Pistofidou & Olmos, 2019; Morpurgo, 2017) to design hybrid crafts workflows and new solutions. Several examples exist in using online configurators for on-demand design and purchase of fashion products (Nervous Systems, 2023; Nike by you, 2023) and craftspeople networking platforms (Italian Artisan, 2023) strenghtening alliances to better reach the market. Interesting processes and solutions for highly manual-based craft sectors such as knitting (Rosner & Ryokai, 2010), crocheting (Smith et al. 2015), embroidering (Flanagan & Fraietta, 2019), and beading (Nicholas et al. 2022) have already explored the possibilities of using I4.0 technologies for detecting, archiving, and teaching traditional crafts expertise, meanwhile creating more accessible data to be passed to future professionals.

Embedding multidimensional values of BM innovation and sustainability

Interweaving traditional artisanal processes with technologies toward multidimensional sustainability dimensions, the

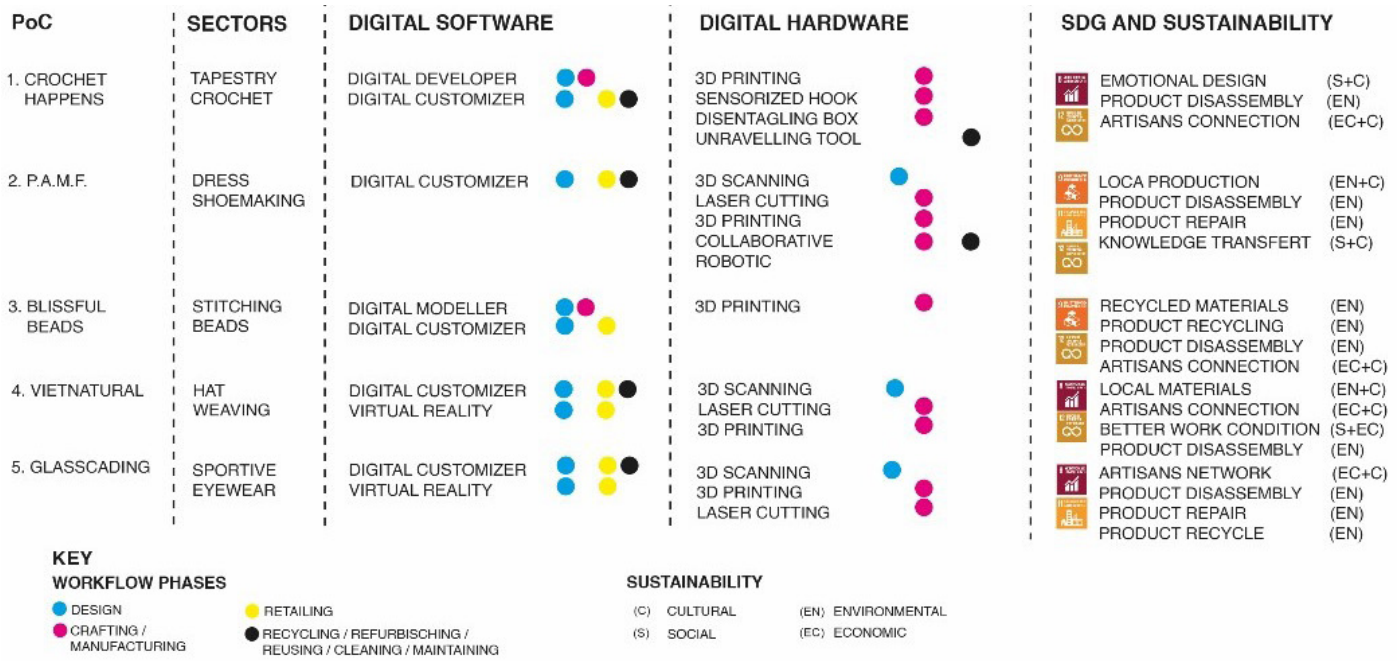

Figure 2. Hybrid sustainable fashion-tech solutions PoCs

PoC	CUSTOMER VALUE PROPOSITION	MARKET APPROACH	VALUE CREATION APPROACH	VALUE CAPTURE / REVENUES	BUSINESS MODEL TYPE
1. CROCHET HAPPENS	customizable crochet bags for self-expression, emotional durability, responsible consumption based on products uniqueness and process transparency	**narrow differentiation** (focus on limited range of customer segments and product differentiation)	. direct interaction of artisans with customers via customization and transparency services on digital platform allowing to follow production process in real-time; . increased efficiency of complex artisanal tapestry crochet process by enabling simpler, and less wasteful on-demand production	. Product sales via digital and physical channels where price is calculated based on degree of customization; . repairing service and online advertisement fees	**Limited product and market portfolio model** (providing some range of customization options of the products for specific customer segments) **to slow resource use by extending product lifespan.**
2. P.A.M.F.	Hyper-personalized (on individual measurements) dress shoes with focus on high quality long-lasting performance and emotional durability enabled by caring and upgrading services to meet different seasonal, functional and aesthetic customer needs	**Broad differentiation/ mass customization** (focus on broad customer base and product differentiation)	. On-demand local personalized production where customer is involved in value co-creation during production and use phase (via post-sales upgrading services); . digital technologies augment traditional artisanal process allowing for better working conditions, improved productivity and customer service	. Product sales via digital and physical channels where price is calculated based on degree of customization; . repairing service and online advertisement fees	**Extended product and market portfolio model** (providing broad range of customization options of products and services for broad customer base) **to slow resource use by extending product lifespan.**
3. BLISSFUL BEADS	Customizable beads and jewelry designs with focus on creativity, self-expression and sustainability (e.g., by using post-consumer and recyclable materials as input resources)	**Narrow differentiation** (focus on one specific customer segment and product differentiation)	Users engagement in co-design and artisanal workshops activities, quicker, easier, more creative and cost-efficient beads production and jewelry assembly process	Physical and digital product sales enabled by virtualization of design process, workshop fees	**Extended product portfolio model** (wide range of customized beads/jewelry designs for one specific customer segment) **to close resource loop by using post-consumer and recyclable materials as input resources.**
4. VIETNATURAL	Custom-tailored headwear enabling self-expression, uniqueness and sustainability (e.g., by supporting crafts sector, enabling less wasteful production and promoting use of bio-based input materials)	**Narrow differentiation** (focus on limited range of customer segments and product differentiation)	On-demand local personalized/customized production, 3D design file sent directly to manufacturer, digital platform connecting artisans, designers and customers enables more simple, faster and less wasteful artisanal production	Physical product sales (hats and repair kits), customization fee, repairing service fee	**Limited product and market portfolio model** (providing some range of customization options of the products for specific customer segments) **to slow resource use by extending product lifespan.**
5. GLASSCADING	Custom-tailored high quality sustainable glasses from fully traceable materials including the product renovation services during the use phase	**Narrow differentiation** (focus on limited range of customer segments and product differentiation)	Product and accompanying renovation services (e.g. maintenance, repair) are provided by the network of artisans connected virtually together and with customers via digital platform, artisanal process is enabled by knowledge-sharing, digital upskilling (education on use of digital technologies, e.g. laser cutting), improved flexibility and lower cost in production and services provision due to use of complementary resources/capacities	Subscriptions	**Limited product and market portfolio model** (providing some range of customization options of the product and services for specific customer segments) **to slow resource use by expanding product lifespan.**

Figure 3. Business models typology of PoCs

solutions encompass different types of value creation: (i) emotional values via increased transparency and storytelling about craft processes, products, and artisans themselves; (ii) cultural value of preserving and spreading the craft ICH; (iii) sustainability/circularity improvements extending product use, and offering repair and recycling services; (iv) increased efficiency, visibility and thus competitiveness of small artisans and their products/services in the mainstream fashion market; (v) customization/self-expression opportunities for to final customers' engaged in co-creation with artisans/designers; (vi) connectivity enabled by technological tools. To monetize the developed hybrid craft solutions, the suggested business models focus on combining products and market portfolio models (e.g., different customized product offerings target different market segments) while aiming to slow resource use and close material loops. These models are acknowledged as part of the digital transformation of creative industries (Feng 2020). Traditional revenue streams based on product sales are complemented by customization, repair, and after-sales support services, whereas one of the suggested business models is subscription-based. More details on the BM typology of PoCs are presented in Figure 3.

Encoding hybrid crafts workflows in new workshops through augmented tools

All projects configured new sustainable and hybrid manufacturing workflows reflected in the design of customised digital software, augmented tools and hardware, workbenches, and spaces to conduct and streamline hybrid crafts activities, representing the affinity between craftspeople and their work environment/material organisation (Oxman, 2007). They supported the design, manufacturing, selling, and repairing phases, establishing a good encounter and negotiation between hand and digital dematerialized activities. The proposed tangible tools augmented with technologies were designed to offer the artisans functional performances, strengthening manufacturing activities in terms of dexterity, process simplification, and gestural digitalization to record crafts activities and encode them to assist craft planning and training. Tools ranged from the

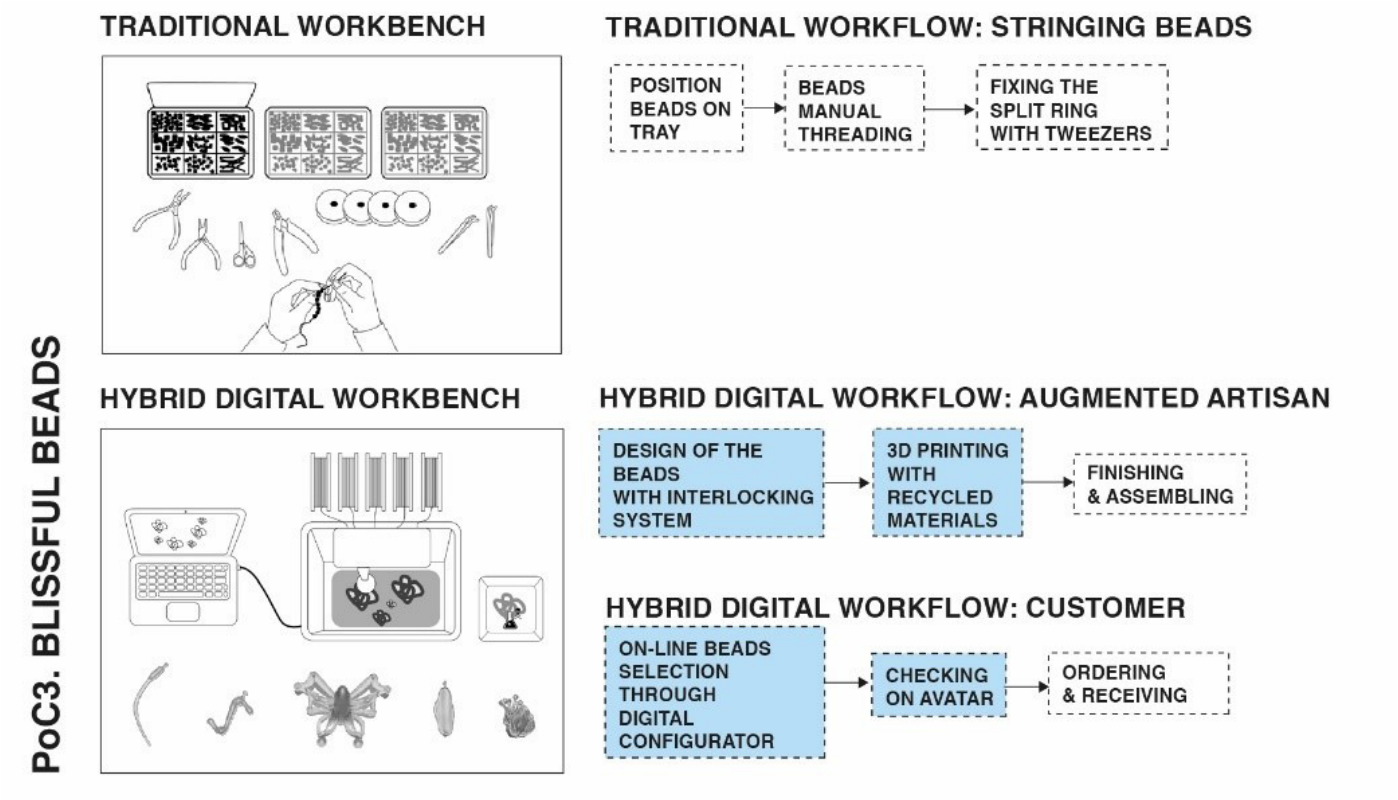

Figure 4. Example of comparison of traditional / hybrid digital workflows and workbench / tools.
PoC3 Blissful beads courtesy of Bachmann B., Xuan G., Lombardi B., Melodia E., Wang B.

smallest integration of sensors and actuators in augmented hooks for enhanced jacquard crocheting (PoC1) to the customization of CR hand-effectors for aiding cyclic assembly and cleaning stages (PoC2). Almost all PoCs equipped the artisans with customised digital parametric software with more intuitive interfaces to simplify artisan-computer interactions. The software is aimed to streamline digital 3D modelling toward digital fabrication (PoC3), develop and engineer made-to-measure craft productions, create networking platforms among artisans in the same sector (PoC4), and aid the configuration of customised craft artefacts by the final consumer. An example of traditional and hybrid workflows, workbenches, and designed solutions is reported in Figure 4. Both digital tools and software were designed to be connected in real-time, aiding both hybrid craft practices and on-demand retail channels, allowing streamlined automation from the design to the crafting of products, thus contributing to the empowerment of craftspeople overproduction.

Connecting stakeholders in the hybrid fashion crafts

Almost all the developed PoC aimed to shorten the distance between stakeholders. Thanks to co-design practices allowed by digital configurators, final customers can access fashion ICH, by watching the workflow progresses of hybrid crafting of their customised products, thus unveiling the complexity, meaning, uniqueness, and beauty of fashion crafts. Therefore, digital technologies enhance the emotional values of craft products, promoting long-lasting connections between users and products, thus contributing to more responsible consumption practices, including extended product use, repair, and recycling. From the artisans' perspective, all PoCs aim to link them with the global fashion markets by preserving their local communities and ICH.

Evolving from multidisciplinary to interdisciplinary skillsets

Students ranked soft skills acquired during the course as 3.75 (based on the Likert scale of 1-5) with particular appreciation of creativity and innovation, collaboration/teamwork, problem-solving, and critical thinking based on sustainability and interdisciplinarity considerations. They rated 4 and above subject-specific skills: fashion-tech design process and methodology, user-centred research, craftsmanship digitalization, and sustainability-oriented business model development. According to students' evaluation, mentoring activities provided: directive guidelines on how to improve the solutions (75%), inspiration and motivation to identify creative solutions (16.7%), contribution to joint co-production of knowledge/ideas in the group projects (33.3%), space for critically and independently reflecting on what improvements are needed (41.6%). Based on students' reflections in group reports, the focus on the design-driven approach complemented by business model thinking toward hybrid crafts innovation was perceived as challenging but beneficial. The business model innovation approach allowed the development of a critical stance on the economic viability of hybrid design of fashion crafts, enabling students reflection on how to attractively frame the value proposition, develop possible revenue streams and consider important partners/collaborations for intended value creation.

Conclusions

By demonstrating new educational models based on interdisciplinary, CBL, and systemic approaches (Bertola and Teunissen, 2018; Pal, 2017), this paper argues that education is a crucial lever to help fashion craftsmanship to stay competitive on the market and preserve its tangible and intangible cultural heritage while promoting sustainability and circularity. Higher education Institutions (HEIs) can drive new learn-

ing experiences based on complementary employment of design, and BM approaches, facilitating industry/multi-stakeholder collaboration and educating future fashion professionals to drive the digital transition towards sustainable hybrid fashion craft solutions.

CBL approach empowers the creation of networks of stakeholders involved/affected by the designed solutions, bridging and bonding the actual craftspeople with the new generation of hybrid fashion professionals across design, technology, and business domains. However, it is crucial to enable stakeholders' involvement at the early stage of research and design for early validations and iterations. According to recent literature, students should develop communication and negotiation skills through visualisations and low-fidelity prototypes to enhance the engagement of the involved stakeholders and craftspeople throughout the process (Mayer et al., 2022).

As demonstrated by delivered PoCs, I4.0 technologies integration in craft workflows offers opportunities for co-designing, co-crafting, and co-learning activities between artisans-students, artisan-technologies, and artisans-customers. If I4.0 technologies were used to make the craft knowledge transfer more engaging, traditional craftspeople still retain fear and doubts about the security of collected gestural data meanwhile crafting (Muller, 2019). Additional reflections on the role of artisans, designers, and computers/machines/robots gaining agency in crafting products are thus necessary to understand the evolution of creative leadership (Stevens, 2020).

The possibilities of exploring interwoven human-machine systems offered by the presented LE have nurtured students' inspirations and skills to design craft artefacts with more complex geometries and augmented precision, while improving its uniqueness through the design of pre-determined configurable parameters, thus impacting aesthetic languages and the hyper-customization of the output (Fig. 4). Provided with design and business joint training, students have gathered an understanding of traditional craft workflows, skills, and ICH, and proposed purposeful integration of technologies to increase the entanglement of traditional and digital crafts processes towards the future competitive and sustainable hybrid fashion craftsmanship sector.

However, the limitations of this kind of LE are related to the limited time to improve and develop high-fidelity prototypes to be tested iteratively with both fashion-tech professionals and traditional craftspeople inside their workshops. Therefore, a follow-up of this LE could be developing a residency model where students could develop functional prototypes and test them directly through on-field study research, and learning-by-doing activities. This Residency approach could amplify, extend and strengthen the implications of digital technologies in transforming fashion craft professional skills while retaining ICH, and in the change of creative processes, workflows, and tools toward more sustainable and meaningful fashion solutions.

References

Bertola, P., & Teunissen, J. (2018) Fashion 4.0. Innovating the fashion industry through digital transformation. *Research Journal of Textile and Apparel*, Vol. 22 No. 4, pp. 352-369. https://doi.org/10.1108/RJTA-03-2018-0023

Bertola P. & Vandi A. (2021) Fashion Design Education Towards Twin Transition. Developing multidisciplinary skills for future professionals. In *Global Fashion Conference 2021*. Poland Cracow ISBN: 978-989-54263-2-4

Bonfanti, A., Del Giudice, M., & Papa, A. (2015). Italian craft firms between Digital Manufacturing, open innovation, and servitization. *Journal of the Knowledge Economy, 9*(1), 136–149. https://doi.org/10.1007/s13132-015-0325-9

British Council. 2020. The Missing Pillar – Culture's Contribution to the UN Sustainable Development Goals. London: British Council. Retrieved March 3rd, 2023 https://www.britishcouncil.org/sites/default/files/the_missing_pillar.pdf.

Brown S. & Vacca F. (2022) Cultural sustainability in fashion: reflections on craft and sustainable development models, *Sustainability: Science, Practice and Policy*, 18:1, 590-600, DOI: 10.1080/15487733.2022.2100102

Burden A., Donovan J., Caldwell G., Teixeira M. B. F (2020) Hybrid digital crafts with collaborative robotics. New Methods in Artisan Patternmaking Using Collaborative Robots and Augmented Reality. *POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research* in Asia (CAADRIA) 2022, Volume 2, 21-30. © 2022 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

Casciani, D., Colombi, C., Chae Y., Jansen K. (2021) Developing a Fashion-Tech Educational model, hybridizing design, engineering, and business management education. In *Global Fashion Conference 2021*, Academy of Fine Arts – University of Warsaw

Casciani D., & Vandi A. (2022) Hypersensing Creative Acts. The Role of Design in Transmitting Intangible Cultural Heritage through Digital Tools. *PAD* 15, 238-263

Casciani D. & Colombi C. (2022) Piloting fashion-tech educational strategies. Proof of Concept for Innovative Fashion-Tech products and Services. Retrieved January 19, 2023. https://fashiontechalliance.eu/images/reports-and-publications/D2-2_PILOTING_FASHION-TECH_EDUCATIONAL_STRATEGIES_PA_compressed.pdf

Digital Manufacturing Lab (2018) Second report Industry 4.0 in Italian SMEs Retrieved January 19, 2023, https://economia.unipd.it/en/en/sites/economia.unipd.it.en/files/Report_DML_Survey2017_ENG.pdf

EC (2023a) Fashion and high-end industries in the EU. Retrieved March 3rd, 2023 https://single-market-economy.ec.europa.eu/sectors/fashion/fashion-and-high-end-industries/fashion-and-high-end-industries-eu_en

EC (2023b) Cultural heritage. Retrieved March 3rd, 2023 https://culture.ec.europa.eu/policies/selected-themes/cultural-heritage

EC (2023c) The EU leather industry. Retrieved March 3rd, 2023 https://single-market-economy.ec.europa.eu/sectors/fashion/leather-industry/eu-leather-industry_en

ETF (2022) Policy brief: The future is in our hands. Recognising emerging skills needs in the craft sector in the EU Neighbourhood and Central Asia. Retrieved January 19, 2023, https://www.etf.europa.eu/sites/default/files/2022-11/Edited_Policy%20brief_craft_EN_FINAL.pdf

ETP (2016) Towards a 4th Industrial Revolution of Textiles and Clothing. A Strategic Innovation and Research Agenda for the European Textile and Clothing Industry. Retrieved January 19, 2023, http://www.technofashionworld.com/files/2016/11/TextileETP_SIRA_public-version.pdf

ETP (2022) Ready to Transform. A strategic research and innovation agenda to underpin the EU strategy for sustainability and circular textiles. Retrieved March 3rd, 2023 https://cdn2.assets-servd.host/deranged-cormorant/production/SIRA_graphical-version-PDF-version.pdf

Euratex (2022) Facts & key figures 2022 of the European textile and clothing industry. https://euratex.eu/wp-content/uploads/EURATEX_FactsKey_Figures_2022rev-1.pdf

Fashion-Tech Open Educational Resources (2022) Retrieved January 19, 2023, https://fashiontechalliance.eu/en/open-resources/open-educational-resources

Feng, L. (2020) The digital transformation of business models in the creative industries: A holistic framework and emerging trends, *Technovation*, 92-93 (2020), 102012. https://www.sciencedirect.com/science/article/abs/pii/S0166497217300536?via%3Dihub

Flanagan, P. J., & Fraietta, A., (2019). Tracing the intangible: the curious gestures of crafts' cultural heritage. In R. Harle, K. Farrahi, & N. Lane (Eds.), *UbiComp/ISWC '19 Adjunct: Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers* (pp. 49-52). https://doi.org/10.1145/3341162.3343799

Fletcher K. (2014) Sustainable Fashion and Textiles. Design Journeys. Routledge

Italian Artisan (2023) Retrieved March 17th, 2023 https://italian-artisan.com/

Jin B. E., & Shin D. C. (2021). The power of 4th industrial revolution in the fashion industry: what, why, and how has the industry changed? *Fashion and Textiles, 8*(1). https://doi.org/10.1186/s40691-021-00259-4

Ma J. J. (2022) Development of education for sustainable fashion design using a challenge-based learning approach, *International Journal of Fashion Design, Technology and Education*, DOI: 10.1080/17543266.2022.2137249

Mayer, G., Ellinger, D., Simon, S. (2022) Involving External Partners in CBL: Reflections on Roles, Benefits, and Problems, In. Vilalta-Perdomo, E., Membrillo-Hernández, J., Michel-Villarreal, R., Lakshmi, G. and Martínez-Acosta, M. (Ed.) *The Emerald Handbook of Challenge Based Learning*, Emerald Publishing Limited, Bingley, pp. 325-344. https://doi.org/10.1108/978-1-80117-490-920221014

McCullough, M. (2015. The hand, across twenty years of digital craft. *TEI 2015*, January 15-19, 2015, Stanford, CA, USA http://www-personal.umich.edu/~mmmc/PAPERS/HandInDigitalCraft.pdf

Morpurgo E. (2018) Crafting Fashion with robots. Retrieved March 17th, 2023 http://eumo.it/Crafting-Fashion-with-Robots-2018

Mosca, F., & La Rosa, E. (2019) 4.0 Technology Within Fashion and Luxury Production, Symphonya. Emerging Issues in Management (symphonya.unicusano.it), 2, 82-94. http://dx.doi.org/10.4468/2019.2.08mosca.larosa

Müller, J. (2019). Assessing the barriers to Industry 4.0 implementation from a workers' perspective. Internation Federation of Automatic Control – PapersOnLine(52/13). Pp. 2189-2194, https://doi.org/10.1016/j.ifacol.2019.11.530.

Nervous System (2023) Retrieved March 17th, 2023 https://n-e-r-v-o-u-s.com/cellCycle/?t=1

Nicholas, C., Forren, J., & Reilly, D. (2022). Augmented: Design and ethnography in/of an architecture, computer science, and textile research-creative collective. In D. Lockton, S. Lenzi, P. Hekkert, A. Oak, J. Sádaba, & P. Lloyd (Eds.), *DRS2022*. Design Research Society. https://doi.org/10.21606/drs.2022.417

Nichols, M. H. & Cator, K. (2009) *Challenge Based Learning White Paper*. Cupertino, California: Apple, Inc.

Nichols, M. H., Cator, K., Torres, M. & Henderson, D. (2016) *Challenge Based Learner User Guide*. Redwood City, CA: Digital Promise

Nike by you (2023) Retrieved March 17th, 2023 https://swoo.sh/3YYsV9b

Oxman, N. (2007) Digital Craft: Fabrication Based Design in the Age of Digital Production. In *Workshop Proceedings for Ubicomp 2007: International Conference on Ubiquitous Computing*, Innsbruck, Austria.

Pal, R. (2017) Sustainable Design and Business Models in Textile and Fashion Industry. In: Muthu, S. (eds) *Sustainability in the Textile Industry. Textile Science and Clothing Technology*. Springer, Singapore. https://doi.org/10.1007/978-981-10-2639-3_6

Performative robotic microfactories (2021) Retrieved January 19, 2023, https://re-fream.eu/pioneers/re-think-manufacturing/

Pistofidou A. & Olmos N. (2018), Esther hates Pvc. Retrieved March 17th, 2023 https://www.nicolasolmos.net/estherhatespvc/

Rosner, D. K., & Ryokai, K. (2010). *Spyn. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/1753326.1753691

Skills 4 Smart TCLF Industries 2030 (2022) Sectoral Skills Strategy for the EU TCLF Industries. Final Report. Retrieved March 3rd, 2023 https://s4tclfblueprint.eu/wp-content/uploads/2022/06/Sectoral-Skills-Strategy-for-the-EU-TCLF-industries.pdf

Smith, T., Bowen, S. J., Nissen, B., Hook, J., Verhoeven, A., Bowers, J., Wright, P., & Olivier, P. (2015). Exploring gesture sonification to support reflective craft practice. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/2702123.2702497

Song, M.J. (2021) Craftspeople's new identity: The impact of digital fabrication technologies on craft practices. *International Journal of Technology and Design Education* (2022) 32:2365–2383. https://doi.org/10.1007/s10798-021-09687-1

Syntropia (2022) Retrieved January 19, 2023, from https://re-fream.eu/pioneers/syntropia/

Stevens, J. (2020) Post Human Craft: A Humble Attempt to Reorient Makers to the Inevitable *Cubic Journal*, 150-165, DOI: 10.31182/cubic.2020.3.29

2030 Digital Compass: the European way for the Digital Decade (2021) Retrieved January 19, 2023, from https://eufordigital.eu/wp-content/uploads/2021/03/2030-Digital-Compass-the-European-way-for-the-DigitalDecade.pdf

United Cities and Local Governance (UCLG). 2010. Culture, the Fourth Pillar of Sustainability. Retrieved March 3rd, 2023 https://www.agenda21culture.net/sites/default/files/files/documents/en/zz_culture4pillarsd_eng.pdf

UNESCO (2003) Convention for the Safeguarding of the Intangible Cultural Heritage Retrieved January 19, 2023, from https://ich.unesco.org/en/convention

UNESCO (2017) Education for Sustainable Development Goals: Learning Objectives. Retrieved January 19, 2023, from https://unesdoc.unesco.org/ark:/48223/pf0000247444