Slow Manufacturing: Its Conceptualisation, Application and Research Agenda

Hideki Kobayashi[1](✉), Haruto Katayama[1], Hidenori Murata[1], Barbara Cimatti[2], and Giampaolo Campana[2]

[1] The University of Osaka, Suita 5650871, Japan
kobayashi@mech.eng.osaka-u.ac.jp
[2] University of Bologna, 40136 Bologna, Italy

Abstract. The manufacturing paradigm is transitioning from Industry 4.0 to Industry 5.0. While Industry 4.0 emphasised IoT technologies to enhance flexibility and efficiency, Industry 5.0 seeks to integrate these advancements with human-centric, sustainable, and resilient approaches. This paper introduces the concept of slow manufacturing, comprising three core elements rooted in craftsmanship, and explores its alignment with the goals of Industry 5.0. Practical and research-based examples from industrialised nations are presented, followed by an analysis of how these cases may be adapted for developing countries. A research agenda is then proposed and structured around the foundational elements of slow manufacturing. This approach suggests that adopting slowness in manufacturing can offer a viable pathway to realising the human-centred ideals of Industry 5.0.

Keywords: Slowness · Craftsmanship · Extra Value Creation · Industry 5.0

1 Introduction

Since the emergence of Industry 4.0 (I4.0) [1], numerous studies and practical applications have explored efficient and flexible manufacturing through technologies such as digital twins and Cyber-Physical Production Systems (CPPS) [2, 3]. However, a new paradigm - Industry 5.0 (I5.0) - is now evolving. Building upon the technological foundations of I4.0, I5.0 introduces concepts of sustainability, resilience, and human-centricity [4, 5]. Although I4.0-related efforts have addressed sustainability and resilience, for example, in decarbonising supply chains [6] and enhancing supply chain resilience [7], many of these approaches lack meaningful integration between human capabilities and autonomous technologies in the context of I5.0.

In this study, we focus on craftsmanship as a vital competence within manufacturing, encompassing not only technical skills but also cultural and social dimensions. In particular, we investigate the concept of slowness in manufacturing [8, 9], which is believed to enhance product value and user satisfaction while supporting worker well-being. The remainder of this paper is organised as follows: Sect. 2 reviews related work on craftsmanship in manufacturing; Sect. 3 introduces the proposed concept of slow manufacturing and its core elements; Sect. 4 presents industrial and academic examples;

H. Kohl et al. (Eds.): GCSM 2025, LNME, pp. 363–371, 2026.
https://doi.org/10.1007/978-3-032-21154-5_40

Sect. 5 discusses adaptation for developing countries; and Sect. 6 proposes a research agenda aligned with the slow manufacturing framework.

2 Related Work

Historically, the Arts and Crafts Movement emerged as a response to the rise of mass production during the first industrial revolution [10]. This movement emphasised using natural materials and traditional craftsmanship, aiming to enhance the enjoyment and artistic integrity of production work. However, it ultimately failed to establish workshop-based production as a mainstream model. In more recent times, the growth of craft-oriented e-commerce platforms, such as Etsy, has rekindled interest in craftsmanship. Yet, these platforms predominantly feature non-essential items, such as jewellery, rather than essential goods.

In the manufacturing industry, several cases have demonstrated the integration of craftsmanship. For example, the Japanese car manufacturer Mazda has incorporated the principles of craftsmanship into mass production through a concept known as "mass craftsmanship" [11]. This approach analyses and systematises the mechanisms behind expert manual skills. In academia, the Digital Triplet (D3) framework has been proposed to capture both explicit and tacit knowledge of craftsmen within digital manufacturing systems [12]. D3 aims to externalise and integrate artisanal skills into automated systems. However, such efforts often overlook the irreplaceable value generated through human touch in manufacturing processes, a value that modern technologies alone cannot replicate.

The earliest formal discussion of "slowness" in the context of factory operations was introduced by Cimatti and Campana, who classified slow manufacturing based on the types of technologies used and the speed of production [8]. In line with their framework, our own research has explored methods for evaluating craftsmanship as a business competence in manufacturing environments [13–16]. While a unified framework has yet to be established, we aim to qualitatively and quantitatively extract the intrinsic value of craftsmanship, not merely for the purpose of automation, but as an independent contributor to product and social value.

Industrial clusters or districts also play an essential role in promoting craftsmanship within manufacturing ecosystems. For instance, Japan's Tsubame-Sanjo region in Niigata Prefecture has a rich history in producing metal household goods and hand tools. At the same time, Sabae is renowned for its eyeglass frame manufacturing [17]. These clusters evolved through the accumulation of specialised artisanal skills and collaborative networks.

In Italy, several industrial districts originate in a distant past, based on the culture and traditions of a specific territory. For example, the popular glass district of Murano-Venice was born in 1291 when the local governor decided to move all the glassmakers of the City to the Murano Island to prevent Venice from the possible fires connected to this kind of activity. The concentration of glassmakers in the same site fostered excellence and the development of new products and techniques, such as the invention of crystal glass in 1450, from which two further Italian inventions had their origin: eyeglasses and telescopes.

One of the most famous Italian industrial districts is the one of sports vehicles located around Bologna and Modena. The “Motor Valley”, as Emilia-Romagna’s sports cars and motorbikes district is called, has its roots in this region’s relevant mechanical industrial tradition. Indeed, in the XV century, the Bologna silk mill was one of the most advanced technologies in Europe, which gave a vocation towards mechanics even before the invention of the car at the end of the XIX century.

3 Concept of Slow Manufacturing

The concept of slow manufacturing is illustrated in Fig. 1 and is composed of three core elements: (1) the integration of craftsmanship and technology, (2) local characteristics, and (3) the creation of extra value.

The first element emphasises the synergistic use of craftsmanship and modern technology, including both traditional machinery and advanced automation systems such as those used in Industry 4.0. As discussed earlier, technologies developed under the Industry 4.0 paradigm aim to improve productivity and operational flexibility. However, many artisanal skills - particularly those involving tacit knowledge and sensory judgment - cannot be replaced by machines. Therefore, manufacturers are encouraged to blend technological efficiency with the human touch of skilled workers, not merely to reduce costs, but to enhance the value of their products. While combining traditional tools and manual labour represents one pattern of slow manufacturing, the concept is broader. In particular, craftsmanship also plays a vital role in promoting worker well-being and supporting the creation of emotionally resonant products in line with human-centred principles of Industry 5.0.

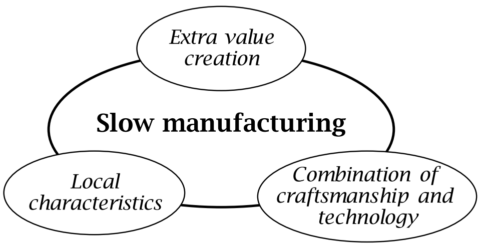

Fig. 1. A concept of slow manufacturing.

The second element concerns the consideration and utilisation of local characteristics. As highlighted in Sect. 2, industrial clusters and districts offer a viable framework for integrating artisanal skills into manufacturing systems. Critical success factors for these clusters include the coexistence of complementary firms, favourable historical and geographical conditions, strong subcontracting relationships, and supportive local government policies. Additionally, using indigenous materials - sourced from the local environment - can add authenticity and uniqueness to the final products.

The third element is creating extra value, which results from the optimal integration of the first two elements. In this context, “extra value” refers not only to a premium price, but also to intangible attributes such as brand prestige or product storytelling. Since such value varies greatly by context and product category, a flexible and case-based approach is essential. Empirical studies that document and analyse successful examples are especially valuable for understanding how slow manufacturing can be effectively implemented across different settings.

4 Industrial Practice and Academic Research

4.1 Industrial Practice

This section presents examples of Small and Medium-sized Enterprises (SMEs) in Japan and Italy that embody the principles of slow manufacturing. These companies demonstrate how craftsmanship can be effectively integrated with automation to enhance product value while preserving artisanal integrity.

Citizen, a leading Japanese watchmaker, exemplifies this dual approach. While automated processes are used for cost-effective mass production, the company reserves the creation of high-end models for skilled artisans, including nationally and regionally certified master craftsmen. This strategy positions craftsmanship as a top corporate priority and differentiates their premium product lines. The company's factory is also located within an industrial district known for precision instrument manufacturing, further reinforcing collaborative advantages.

Kaneko Optical, based in Sabae - a famous city for its eyeglass manufacturing - represents another notable example. The company has gained popularity among ethically conscious consumers for its handcrafted products and meticulous attention to detail. At the same time, Kaneko Optical invests in research and development to enhance its production capabilities, aiming to find the optimal balance between manual techniques and specialised automation. This includes the development of proprietary technologies tailored to their artisanal workflow.

Ferrari, Lamborghini, Maserati and Pagani are the most significant brands for sports cars and Ducati for motorbikes, located in the already mentioned Italian "Motor Valley". Vehicles are complex products that require high-quality materials and processes to be fabricated and assembled. In all these medium-sized enterprises, craftsmanship and advanced technologies join to manufacture excellent vehicles. Local vocational skills in mechanics, good technical schools, and a locally diffused entrepreneurial spirit have allowed the establishment of factories where vehicles are manufactured, prioritising attention and quality over time reduction. The craftwork component is expressed by the capability of workers to take care of all the details using an artisanal manual approach, which adds significant extra value, making each vehicle unique and integrated into the use of advanced materials and processes.

Another case of an Italian SME where the slow manufacturing approach is adopted is Babbi, a company producing chocolates and creams. Being nicknamed the "Ferrari of food", Babbi chooses slow processes to guarantee taste and the superior quality of its products. For example, in the case of the production of caramelised figs, the company has evaluated a modern pasteurisation system as a possible process innovation because it lasts a few hours. However, based on the expected product quality, the longer traditional cooking method lasting several hours has been finally preferred because this method assures the best taste of the figs.

All these examples reflect the three core elements of slow manufacturing outlined in Sect. 3: the integration of craftsmanship and modern technology, the influence of regional characteristics (industrial clustering), and the pursuit of extra value creation through authenticity and narrative-rich products.

4.2 Academic Research

In academic research, efforts have been made to identify which manufacturing processes should remain reliant on artisanal skills and which are more suitable for automation. One such method involves a structured classification process, consisting of the following four steps:

Step 1: Investigate the production processes of benchmark companies that successfully integrate craftsmanship. These processes are categorised into three types:

- Skill-dependent processes. Where the artisan's expertise significantly influences product quality and value.
- Skill-neutral processes. Where worker skill is used but has minimal impact on the final value.
- Automated processes. Already optimised through mechanisation or digital technologies.

Step 2: Evaluate each process using qualitative criteria, such as whether it involves handcrafting or produces visually distinct or emotionally appealing variations in the product finish.
Step 3: Apply Hayashi's Quantification Theory Type II [18] to the qualitative assessments. This technique maps each process into a discriminant space, where the centroid of each classification category is calculated.
Step 4: Classify a target process by locating its position in the discriminant space based on qualitative evaluation, then assign it to the closest category centroid.

As a practical example, Fig. 2 illustrates the results of applying this classification method to an eyeglass manufacturing company. Training data were derived from best practices in knife and glass bottle production. Three specific processes - frame shaping, engraving, and temple bending - were identified as differing from current company practices. When these results were presented to the factory manager, the proposal to automate engraving was deemed infeasible due to its complexity and craftsmanship requirements. However, the recommendations to automate shaping and bending processes were considered promising. For all other processes, the proposed classifications aligned well with current practices, validating the method's effectiveness.

Although this methodology shows potential, further verification and expansion across other industries and regions is needed to generalise its applicability. Nevertheless, it offers a valuable tool for strategically integrating craftsmanship and automation in a balanced, human-centred way, consistent with the ideals of Industry 5.0.

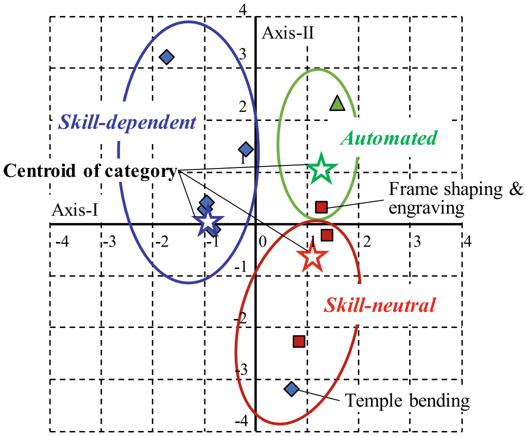

Fig. 2. Classification result of target manufacturing processes based on learning from the best practice of slow manufacturing.

5 Discussion

5.1 Extending the Network of Slow Manufacturing to Developing Countries

In many developing countries, particularly in Southeast Asia, large domestic manufacturing enterprises are scarce, and economic constraints often hinder investment in advanced manufacturing technologies. Consequently, SMEs have emerged as the primary actors in the manufacturing sector.

One viable approach for SMEs in such regions is the adoption of Appropriate Technology (AT). This approach focuses on producing original local products using naturally available materials such as wood, bamboo, and clay, typically in small production volumes. Workers are usually recruited from the surrounding community, resulting in the preservation of low-cost, indigenous, and culturally rooted technologies.

For instance, Mitti Cool in India manufactures clay-based, non-electric refrigerators designed for individuals who cannot afford conventional electric appliances [19]. This product addresses local challenges such as economic hardship and unstable electricity supply by utilising traditional materials, older machinery, and local labour. Similarly, Magno in Indonesia produces handcrafted wooden goods, with all employees sourced from the local area [20].

Slow manufacturing and AT share several features, including non-mass production principles, emphasis on worker satisfaction, and the creation of extra value through culturally embedded narratives. However, key differences also exist. Unlike AT, slow manufacturing aims to combine craftsmanship with advanced technologies, such as those developed under the Industry 4.0 paradigm, to enhance value creation and production efficiency. Moreover, industrial clusters that play a critical role in the slow manufacturing model are generally underdeveloped in emerging economies.

To enable the spread of slow manufacturing in these regions, it is essential to support the development of industrial districts and invest in engineering education and technical infrastructure. These measures would help bridge the technological gap and enable the integration of human skills with modern innovations in a contextually appropriate and sustainable manner.

5.2 Research Agenda

To advance the practical and theoretical foundation of slow manufacturing, we propose a research agenda focusing on three key areas:

Combination of Craftsmanship and Technology. As demonstrated in Sect. 4.1, further refinement of analysis methods is needed to identify better optimal combinations of manual skills and both traditional and modern technologies. Particular attention should be given to positively evaluating the time spent on artisanal processes that significantly contribute to value creation, rather than viewing such time as inefficiency.

Local Characteristics. Each successful industrial district evolves with its own unique configuration [19]. Therefore, it is crucial to identify and apply region-specific models that support slow manufacturing. This requires the continuous collection and analysis of case studies focused on artisanal skills, intending to identify compatible structural patterns for various local contexts.

Extra Value Creation. A deeper understanding of how slowness contributes to creating extra value is necessary. This value is twofold:

- On the worker side, indicators may include per-person sales or the subjective well-being derived from meaningful work.
- On the user side, value manifests as emotional attachment or a sense of timelessness toward products crafted by artisans. This emotional connection can extend product lifespan and reduce waste, thereby enhancing sustainability.

Moreover, fostering skill-centred product development is critical. If slow manufacturing enterprises can leverage craftsmanship to explore new product directions or niche markets, core artisanal competencies can be preserved and carried forward into the future.

It should be noted that these research areas are interrelated. Thus, a cyclical approach combining the development of new analytical methods with comprehensive case studies, spanning individual companies, regional clusters, and international comparisons, is recommended to achieve a more integrated understanding of slow manufacturing.

6 Conclusions

This paper proposed a concept of slow manufacturing applicable to the framework of Industry 5.0 and introduced examples of its application in industrialised countries, both in corporate practice and academic research. The discussion then extended to the potential for implementing this concept in developing countries, followed by the presentation of a future research agenda. Slow manufacturing offers a promising solution to the challenge of integrating human handwork with Industry 4.0 technologies, contributing to greater diversity in manufacturing approaches. Moving forward, we aim to pursue further studies that enhance the well-being of both workers within production systems and the users of the products they create.

Acknowledgement. A portion of this work was supported by Bilateral Collaborations of JSPS (JPJSBP120229925).

References

1. Kagermann, H., Wahlster, W.: Ten years of Industrie 4.0. Sci **4**(3), 26–35 (2022)
2. Schleich, B., et al.: Shaping the digital twin for design and production engineering. CIRP Ann. Manuf. Technol. **66**, 141–144 (2017)
3. Monostori, L., et al.: Cyber-physical systems in manufacturing. CIRP Ann. Manuf. Technol. **65**, 621–641 (2016)
4. Xu, X., et al.: Industry 4.0 and Industry 5.0 – inception, conception and perception. J. Manuf. Syst. **61**, 530–535 (2021)
5. Van Erp, T., et al.: Industry 5.0: a new strategy framework for sustainability management and beyond. J. Clean. Prod. **461**, 142271 (2024)
6. Sindhwani, R., Hasteer, N., Behl, A., Chatterjee, C., Hamzi, L.: Analysis of sustainable supply chain and Industry 4.0 enablers: a step towards decarbonization of supply chains. Ann. Oper. Res. (2023). https://doi.org/10.1007/s10479-023-05598-7
7. Qader, G., et al.: Industry 4.0 enables supply chain resilience and supply chain performance. Tech. Forecasting Soc. Change **185**, 122026 (2022)
8. Barbara, C., Campana, G.: The slow factory: a new paradigm for manufacturing. In: Proceedings of the 11th GCSM, pp. 273–277 (2013)
9. Kobayashi, H.: A concept proposition of slow-manufacturing. In: Proceeding of the JSME-MSD, pp. 136–138 (2022). (in Japanese)
10. Krugh, M.: Joy in labour: the politicization of craft from the arts and crafts movement to Etsy. Can. Rev. Am. Stud. **44**(2), 281–301 (2014)
11. Adachi, N.: Development of mass craftsmanship production system. Mazda Gihou **36**, 154–158 (2019). (in Japanese)
12. Umeda, Y., et al.: Digital triplet and its implementation on learning factory. IFAC PapersOn-Line **55**(2), 1–6 (2022)
13. Campana, G., Cimatti, B.: Measures and methods for a new taxonomy in manufacturing enterprises. Procedia CIRP **26**, 287–292 (2015)
14. Campana, G., Cimatti, B., Melosi, F.: A proposal for the evaluation of craftsmanship in industry. Procedia CIRP **40**, 669–674 (2016)
15. Campana, G., Mele, M., De Bortoli, L., Cimatti, B., Kobayashi, H.: Evaluation of competencies for a sustainable industrial environment. In: Kohl, H., Seliger, G., Dietrich, F. (eds.) Manufacturing Driving Circular Economy. GCSM2022. LNME (2023). https://doi.org/10.1007/978-3-031-28839-5_93
16. Irino, Y., Murata, H., Kobayashi, H., Campana, G.: An analysis method considering manufacturing skills and technologies toward slow manufacturing. In: EcoDesign for Circular Value Creation, vol. I, pp. 547–561. Springer, Cham (2025)
17. Yamawaki, H.: The evolution and structure of industrial clusters in Japan. Small Bus. Econ. **18**, 121–140 (2002)
18. Hayashi, C.: On the quantification of qualitative data from the mathematico-statistical point of view. Ann. Inst. Stat. Math. **2**, 35–47 (1950)

19. Mitti Cool. https://mitticool.com. Accessed 15 Apr 2025
20. Magno. https://magno.works. Accessed 15 Apr 2025