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Organization of Production Processes in Small Woodworking Business in the USA

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ABSTRACT

Small woodworking companies are an important part of the U.S. furniture manufacturing business, especially when it comes to custom furniture or low-volume runs. Unlike their larger-scale, industrial counterparts, however, small woodworking operations have limited resources, are characterized by higher levels of product variation, and utilize a much greater proportion of manual processes. Therefore, organizing production workflows becomes more complex than in their industrial counterparts. Research into the U.S. furniture manufacturing industry has traditionally focused on large-scale industrial manufacturing, automation, and technological improvements, while generally ignoring the operational constraints faced by small-scale manufacturing operations. This research addresses this void by examining how small woodworking businesses organize production using both theoretical knowledge from manufacturing research and real-world industry experience. This research examined major production stages, including (1) raw materials preparation; (2) machining; (3) assembly; and (4) finishing, as well as how digital technologies such as computer-aided design (CAD), computer numerical control (CNC) systems, etc., improve production workflow efficiencies. Special emphasis was placed on the role of digital technologies in coordinating production processes, ensuring quality, and managing the consistent production of customized products. The results of the research indicate that the effective organization of production processes in small woodworking businesses is dependent upon the implementation of structured workflow management, accurate material flow, and quality control at each step of the production process. In addition, the research provides a practical, process-oriented framework for improving production efficiency and product quality in small-scale furniture manufacturing.

KEYWORDS

woodworking production systems, small-scale manufacturing, custom furniture production, production workflow organization, furniture manufacturing processes, manufacturing efficiency.

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Організація виробничих процесів на малих деревообробних підприємствах у США

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СТАТТЯ

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АНОТАЦІЯ

Невеликі деревообробні компанії є важливою частиною меблевого бізнесу США, особливо коли йдеться про меблі на замовлення або невеликі обсяги виробництва. Однак, на відміну від своїх більш масштабних промислових аналогів, невеликі деревообробні підприємства мають обмежені ресурси, характеризуються вищим рівнем різноманітності продукції та використовують набагато більшу частку ручних процесів. Тому організація виробничих робочих процесів стає складнішою, ніж у їхніх промислових аналогах. Дослідження меблевої промисловості США традиційно зосереджувалися на великомасштабному промисловому виробництві, автоматизації та технологічних удосконаленнях, загалом ігноруючи операційні обмеження, з якими стикаються дрібномасштабні виробничі підприємства. Це дослідження вирішує цю прогалину, досліджуючи, як невеликі деревообробні підприємства організовують виробництво, використовуючи як теоретичні знання з досліджень у галузі виробництва, так і реальний галузевий досвід. У цьому дослідженні розглянуто основні етапи виробництва, включаючи (1) підготовку сировини; (2) механічну обробку; (3) складання; та (4) оздоблення, а також те, як цифрові технології, такі як системи автоматизованого проєктування (САПР), системи числового програмного керування (ЧПК) тощо, підвищують ефективність виробничих робочих процесів. Особливий акцент було зроблено на ролі цифрових технологій у координації виробничих процесів, забезпеченні якості та управлінні стабільним виробництвом продукції на замовлення. Результати дослідження показують, що ефективна організація виробничих процесів на малих деревообробних підприємствах залежить від впровадження структурованого управління робочими процесами, точного потоку матеріалів та контролю якості на кожному етапі виробничого процесу. Крім того, дослідження пропонує практичну, процесно-орієнтовану основу для підвищення ефективності виробництва та якості продукції у дрібносерійному виробництві меблів.

КЛЮЧОВІ СЛОВА

деревообробні виробничі системи, дрібносерійне виробництво, виробництво меблів на замовлення, організація виробничого процесу, процеси виробництва меблів, ефективність виробництва.

1. Introduction

The U.S. woodworking and furniture manufacturing industries are comprised of both very large-scale manufacturers producing standard, mass-produced items (and therefore, controlling a significant portion of the market) and smaller woodworking shops, which produce high numbers of one-of-a-kind or very low-volume products for their customers.

Compared to large-scale industrial manufacturers, these enterprises have two main characteristics: they can produce a variety of products on a relatively small scale; and they use highly variable materials (e.g., wood), which often cannot be fully automated. Therefore, small woodworking businesses must develop flexible but organized production systems that meet the demands of their customers for higher-quality goods at faster lead times.

To date, most of the research in furniture manufacturing has focused on large-scale industrial manufacturing systems, ways to optimize technology, and how to improve efficiency through automation. Research highlights the importance of machining technologies, digital design software and the integration of various production systems in improving productivity and quality. On the other hand, there is little evidence of studies examining the organization of production processes in small woodworking businesses, where the nature of the production environment is very different than in industrial settings.

In small-scale woodworking business environments, production efficiency will depend upon the company's organizational ability to coordinate workflow, coordinate production stages and maintain quality consistency in the production of customized goods. Additionally, companies without formal production organizations may experience problems with inefficient production, including wasted materials, delayed production times and inconsistent finishes.

This paper attempts to assess the organization of production in small woodworking businesses in the United States. This paper examines the structure of production workflow, the roles of digital technologies, and the challenges involved in the production of custom furniture. This study intends to create a process-oriented view of enhancing efficiency and quality in small-scale woodworking production, based on both theoretical research findings and practical experience in the industry.

Unlike existing studies that primarily focus on technological advancement and large-scale manufacturing systems, this study adopts a production-organization perspective grounded in real operational environments.

The novelty of this research lies in its focus on process coordination, human-centered decision-making, and workflow integration in small-scale, high-variability production systems, which remain underrepresented in current literature.

2. Literature Review

2.1. Transformation of Furniture Manufacturing Systems: From Craft to Hybrid Production Models

The development of furniture manufacturing represents a movement toward both increased technology and structuring of manufacturing from a craft-based approach toward greater mechanization and systematization. Traditional woodworking was based upon a craftsman's skill set and utilized decentralized workflows. Thus, the quality and efficiency of the products produced by traditional woodworking practices was dependent upon the craftsman who was producing the product. However, Ratnasingam has identified a move toward utilizing engineering principles, process standards, and optimizing workflow, which represent a more structured form of production [12].

Despite the increase in use of structurally integrated manufacturing approaches, there is also evidence of a non-uniform application of these new forms of manufacturing. Specifically, while larger-scale furniture manufacturers are adopting fully automated and standardized manufacturing systems, smaller to medium-sized enterprises (SME) are using hybrid systems. Hybrid systems incorporate both manual processes and selected technologies. The difference in the structure of the manufacturing systems being used by large versus small/medium-sized manufacturers is most apparent in the U.S. furniture manufacturing sector. In the U.S. furniture manufacturing sector, there are ongoing innovations occurring in addition to the continued use of traditional craft-based manufacturing techniques [13].

However, it appears that many researchers are assuming that the evolving manufacturing trends represent a linear progression toward automation and industrial efficiency. However, such assumptions may be based on the experiences of larger manufacturers and do not capture the constraints imposed by the structure of small woodworking businesses. Specifically, for many small woodworking businesses, it is not possible or even desirable to adopt fully industrialized production methods. Therefore, the current body of research does not accurately represent the hybrid nature of the production systems that are typical of small-scale custom furniture manufacturing.

2.2. Digitalization and Industry 4.0: Opportunities and Structural Limitations

A large body of recent research has concentrated on how Industry 4.0 technologies can be integrated into woodworking and furniture manufacturing processes. Most of the research found that digital tools – like CAD systems, CNC machines, and the ability to monitor production data - are important tools for improving precision, efficiency, and overall process integration [4; 17].

In addition to providing an expanded view of the potential impacts of digital transformation, other research has identified some of the additional effects of digitalization. For example, Rame et al. note that digitalization allows for more flexible responses to changing demands in furniture production, especially in situations where customized products are being manufactured [11]. Similar arguments have been made about "factory of the future" principles, which include digitalized production systems and adaptable production systems [9].

However, it is clear from the literature that there is an apparent contradiction. Technological capabilities have been discussed at length, yet most empirical research suggests that actual implementation of the technology is variable. For example, Kırklıkçı demonstrated that employees' knowledge of and willingness to adopt Industry 4.0 technologies varies greatly, suggesting that financial capability is not the only factor limiting the adoption of Industry 4.0 technologies - organizational capabilities and workforce competency are also limiting factors [7]

Furthermore, Landscheidt et al. noted that when robotic automation is technically possible, the adoption of the technology in woodworking industries is limited because of the variability of products made with the technology, the variability of the materials used in the products, and the difficulty of using robots to handle natural materials such as wood [8].

Overall, the findings of the studies suggest that digitalization alone will not solve the production inefficiencies experienced in small woodworking companies. The research appears to place too much emphasis on technological solutions, while minimizing the role of process organization, workflow coordination, and human factors in the operation of production systems.

2.3. Production Optimization and Process Efficiency in Woodworking

The engineering and systems perspectives of optimizing production processes have received extensive attention. Hosseini and Peer provide a broad review of the use of optimization techniques in wood products manufacturing, which includes the use of production planning and resource allocation, along with process modeling to increase efficiency [6].

Additionally, Ratnasingam highlights the role of structured production engineering techniques, including workflow sequencing, machine utilization, and integrating quality control [12]. These types of optimization techniques are mainly applicable to controlled production environments where processes can be standardized and variations in the production process are minimal. However, the application of these models to small-scale woodworking businesses, or custom furniture production companies that have high variability in design, materials and production needs, is not feasible.

The optimization models described previously also include various production phases (drying, machining, and finishing), which introduce additional complexities. As an example, Bowe et al. indicate that highly technical processes such as kiln drying require specialized knowledge and training, especially in areas such as the Northeastern United States [3]. Therefore, the process-specific expertise required for each of these production phases is typically not included in generalized optimization models.

2.4. Flexible Manufacturing and Customization: The Mini-Factory Paradigm

Flexible manufacturing approaches, which allow for both efficiency and customization, have been developed through the use of flexible manufacturing systems (FMS). These include mini-factories and close-to-the-customer production systems. Barni et al. suggest that mini-factories are small-scale, integrated production units capable of producing a wide range of custom products with faster response to customer requests [2]. This is part of a larger trend towards mass customization and decentralizing production.

Landscheidt and Kans demonstrate how FMS can improve adaptability in the wood product industry. However, the majority of the current literature assumes that there will be sufficient technological integration and process standardization to achieve the benefits of FMS, which is typically not the case in small-scale woodworking operations [9]. Most small woodworking companies currently operate with non-integrated workflow processes, limited automated technology and manual coordination of different parts of the production process.

Therefore, much of the literature presents an idealized view of flexible manufacturing that does not accurately represent the day-to-day reality of small-scale production. As a result, there is currently a lack of research focused on empirically examining how flexibility is practiced within constrained resources.

2.5. Sustainability and Resource Efficiency in Woodworking Production

Furniture manufacturers increasingly incorporate sustainability into their production process, focusing on circular economies, reducing waste and using resources efficiently. Awan and Sroufe emphasize the use of circular economy principles when developing business models that provide minimal waste and increase the life cycle of products [1]. Woodworking, like other forms of manufacturing, also creates opportunities for improving material efficiency and waste management.

De Souza Pinho et al. compared the environmental effects of managing wood wastes through recycling or recovering energy versus sending wood wastes to landfills. They found that both recycling and recovering energy have large positive effects on the environment relative to landfilling [5]. In terms of product design, Zhang et al. note that designers can create more sustainable products by designing for recyclability [18]. Additionally, Schubert et al. explain that sustainable production involves many variables due to the natural variations inherent in all raw materials. While this body of work provides insight into how to make sustainable production systems operational in theory, the current state of sustainable practice among SMEs varies widely [14].

Purwandani and Michaud identified several reasons why some SMEs do not adopt sustainable practices, including cost, lack of knowledge or experience, and limited availability of necessary resources [10]. Sedliačikova et al. provided additional information by indicating that the absence of established benchmarks complicates the process of implementing green growth initiatives in woodworking companies [15].

Furthermore, Viholainen et al. argued that sustainability should be approached from an ecosystem perspective. This would involve cooperation between multiple stakeholders within supply chains. Such an approach could be challenging for independent small businesses [16]. Overall, although there is extensive research regarding sustainability, there is still much to explore concerning the practical application of sustainability into the day-to-day operations of small woodworking businesses.

2.6. Synthesis and Research Gap

The review of current literature has identified the following key shortcomings in the analysis of production systems:

1. Scale bias in production system research

Research on production systems, for the most part, has focused on large-scale industrial manufacturing systems, and very little research has been conducted in relation to small woodworking enterprises, which can be characterized as being highly variable and producing at low levels of volume.

2. Technological determinism

Digitalization, automation, and Industry 4.0 are technologies that are presented as solutions to production problems; however, empirical evidence indicates that adoption of these technologies is constrained and uneven in SME's.

3. Deficiencies in process-level analysis

Production optimization and flexible manufacturing are common discussion topics; however, in sufficient extent, the literature is focused on the practical organization of production flows, coordination between different stages in the production system, and the challenges actually encountered in day-to-day production operations.

4. Differentiation in the research domain

The research domains of sustainability, digitization, and efficiency are usually examined separately, with little or no research integrating all of the above-mentioned areas of interest into a single understanding of production systems.

5. Relatively limited incorporation of perspectives from practitioners

Literally none of the current studies include any detailed insights from personnel who actively participate in the production processes; this creates a lacuna between theoretical models and the actual implementation of production systems.

2.7. Contribution of This Study

This paper addresses these gaps by:

• focusing specifically on small woodworking businesses in the United States

• analyzing production processes as integrated workflows rather than isolated stages

• emphasizing the role of process organization alongside technological tools

• incorporating practical industry experience to bridge the gap between theory and real-world production

By doing so, the study provides a more comprehensive and practice-oriented understanding of how production efficiency and quality can be achieved in small-scale woodworking manufacturing.

3. Problem Statement

The problem addressed in this study is the lack of systematic approaches to organizing production processes in small woodworking businesses operating under conditions of limited resources, high product customization, and predominantly manual production.

4. Methods and Materials

4.1. Research Design and Approach

The research methodology employed in this study is a qualitative, practice-based research design that examines how the processes of manufacture within small woodworking enterprises are organized. Due to the fact that small-scale furniture manufacture exhibits significant variation, customization, and low levels of standardization; therefore, purely quantitative or model-based approaches are unable to capture the complexities present in real-world production settings. A qualitative framework will allow for a more detailed examination of workflow structures, process dependencies, and operational constraints than could be achieved through a purely quantitative or model-based approach.

This study has been conducted using a case-informed analytical approach, which draws upon academic literature relating to the subject area, along with first-hand practical experience gained from working in the U.S. woodworking industry. Studies concerned with optimizing production processes, utilizing simulation models or abstracted representations of production systems [6], focus primarily upon theoretical aspects of production processes. In contrast, this study examines the production processes used in practice and seeks to identify the inefficiencies, coordination problems, and quality-related problems that are typically not evident in theoretical models.

Through the integration of both theoretical perspectives and observations made from the field of practice, the study has adopted an interpretative research paradigm. Therefore, it views production systems not simply as technical systems, but rather as social-technical systems that are formed through the actions of individuals making decisions, the physical characteristics of materials, and the coordination of workflows.

This study employs a qualitative, case-informed research design based on structured observation of real production environments. The approach integrates direct participation in production processes, workflow documentation, and analytical interpretation of operational practices.

Rather than relying on abstract modeling, the study focuses on empirical observation of production systems as they function under real constraints, including variability of materials, customization requirements, and limited formal planning.

4.2. Empirical Context

The empirical base of this study was developed from the authors' personal experiences working in two small woodworking firms in the U.S., Moda Woodworking and Zalitok Fabrication LLC. The two different firms provided two unique views of organizational approaches to production in similar small-scale manufacturing settings.

Moda Woodworking produces custom interior furniture, primarily custom kitchen cabinets and residential wood components. As such, it has a very high level of precision in its production processes, complex finishing steps, and very high standards for finish quality. On the other hand, Zalitok Fabrication LLC produces outdoor furniture utilizing a combination of wood and metal fabrication. This requires consideration of structural durability when exposed to the outdoors, and hybrid materials with wood and metal.

At the time of the sampling event (since November 2023), MODA Woodworking reported having a staff of 13 personnel working on 8–12 residential projects monthly, primarily within the range of 2,500 sq ft. During the study cycle, we saw measurable growth in the company, up to and including 17 employees and production capacity increased to 15–20 projects/month. Simultaneously, this work encompassed traditional building projects to include large-scale custom commissions ranging from \$250,000 to \$300,000 with sizes of up to 8,000 sq ft. A dynamic environment that allowed the researchers to study variations in production organization in the context of scale and complexity occurred.

The use of both companies allowed the researchers to gain a broadened understanding of how workflow organization and production issues are similar or differ in various production environments and at the same time maintain a focus on the commonalities associated with small-scale, customized manufacturing systems.

The observational period spans from November 2023 to December 2024, during which production processes across multiple projects were analyzed.

The study includes observation of approximately 30–50 projects across different levels of complexity, including high-value custom residential installations.

4.3. Data Collection

The data that is collected for this study is a result of long-term interaction with production systems and therefore is largely qualitative. The method is built upon observation and documentation of production processes, which also provides the researchers with experience-based knowledge by allowing them to actively participate in the manufacturing processes.

During observation, the researchers followed the major phases of the production process – preparation of materials, machining, assembly, finishing, and inspection - and paid particular focus to the ordering of work tasks; the relationships of one task to another; and the communication between each phase of the production system. Through these observations, the researchers were able to determine areas of bottlenecking and inefficient operation within the production process, as well as locations of error occurrence. In addition to qualitative observations, selected process stages were assessed using time-based measurements, particularly in the final inspection and shipping phase, where workflow duration served as an indicator of process efficiency.

Documented records of the production workflow were developed throughout the course of the study using process mapping and an examination of each production stage. This documentation tracked the movement of materials, identified the critical control points at each stage of production, and examined how deviation from the standard operating procedure affects overall production. Documentation of this type fits into a larger framework of process-oriented methodologies used in production engineering [12], but extends this to smaller-scale, less formalized production environments.

One of the largest components of the methodology for this study is the inclusion of knowledge provided by practitioners as a result of their hands-on experience in producing goods. Practitioners participated in various aspects of the production process – such as assembly, application of spray finishing techniques, and quality control procedures – to provide the researchers with experience-based information about what occurs during production. Experience-based information, such as the behavior of materials during finishing or operational limitations placed on workflow coordination, is difficult to obtain using traditional research methodologies.

Data were collected through a combination of:

- direct observation of production workflows
- participation in production activities (assembly, finishing, quality control)
- process mapping of material and workflow movement

• time-based measurements at selected production stages (e.g., inspection and loading). Particular attention was given to identifying workflow bottlenecks, sources of variability, and points of defect propagation across production stages.

4.4. Analytical Framework

The analysis has a process-based model and will examine production as a series of linked stages as opposed to independent processes. The analysis at each stage of the production process is based upon the role of the individual process within the total flow process. The focus will be on the effects that decision-making and results from each stage have on other stages in the process.

There are five main stages in the furniture manufacturing process: material preparation, machining, assembly, finishing, and quality control. These stages are viewed as part of an integrated and dynamic process with feedback mechanisms (for example, reworking due to defects caused by finishing), which significantly impact the efficiency of the production process.

For each of these stages, the analysis will evaluate the structure of the workflow, resource use, variability, and the interaction with adjacent stages. This will allow for identifying the causes of systemic inefficiency in the process (for example, if the machining process does not produce a product accurately enough for the finishing process, or if there is not adequate surface preparation before coating).

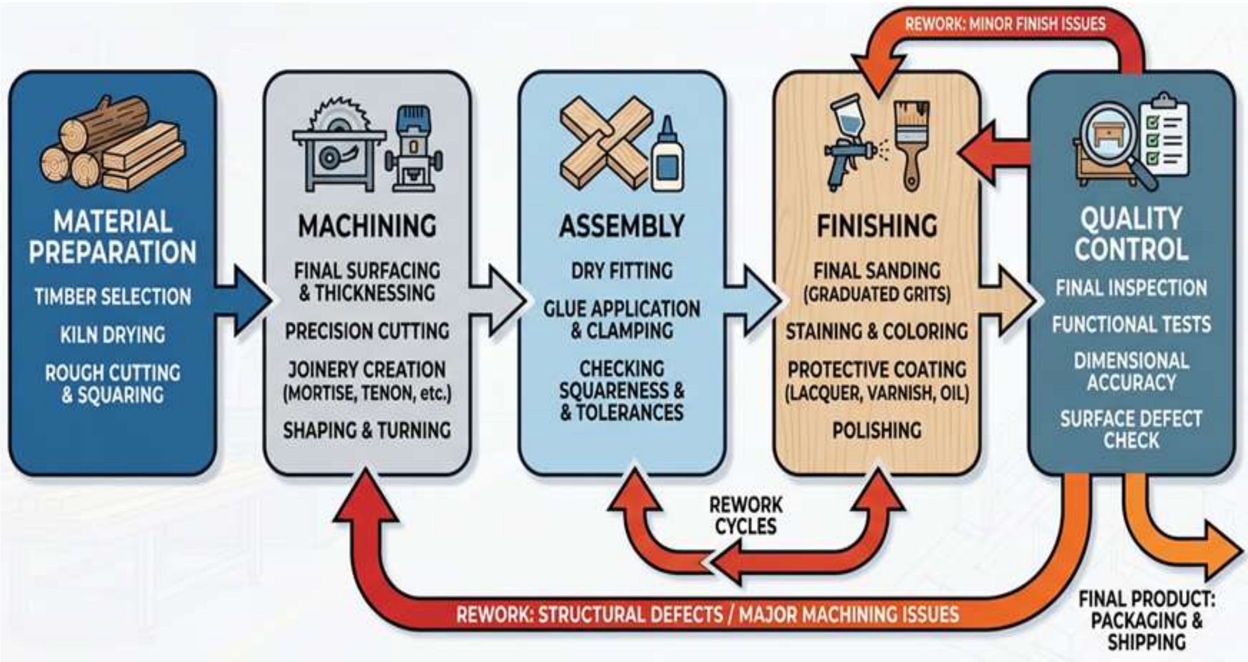

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Figure 1. Eastern Partnership Index 2021–2025

Source: Production Workflow in Small Woodworking Businesses.

4.5. Reliability and Limitations

Qualitative and practice-based approaches provide detailed insight into actual production settings; however, they also present limitations. The findings are based on a limited number of cases that limit the ability to generalize. However, the intent of this research is not statistical generalization. Instead, it is to develop analytical insights regarding the structure of production organizations.

Practitioner experience may introduce subjective biases for the researcher since the researcher is directly involved with the process being studied. Subjective bias is mitigated through systematic observation and relating study findings to established literature in woodworking and manufacturing systems.

Finally, this research is reflective of the specific context of small U.S. woodworking firms. Although some findings from this study may have relevance to similar firm types, the specific characteristics of regional practices, labor markets, and technological diffusion can limit the generalizability of the findings.

5. Results

The findings are organized into key operational patterns observed across the studied production environments. These patterns reflect recurring structural characteristics rather than isolated events. Operational improvements were observed in later-stage coordination processes, particularly in inspection and loading, where structured workflow interventions significantly reduced processing time. The production process of wood-working enterprises follows a generally known sequence of raw material preparation, manufacturing (machining), assembly, finishing, and quality control. However, the described sequence is mostly not realized in a linear sequence but rather as a flexible and cyclically connected system. Thus, there is no clear linearity in the flow of production. Loops are formed between the different production stages, especially between the finishing phase and previous preparation steps and between the assembly and machining steps. Therefore, production is carried out in a cycle rather than in a linear fashion.

On the other hand, empirically, the studied enterprise showed significant operational growth although it lacked formal production systems. Production volume increased from around 8–12 to 15–20 projects a month and the workforce grew from 13 to 17 persons. Simultaneously, the company conducted uninterrupted daily shipping operations, which was further testament to a higher level of workflow coordination and throughput capacity.

One of the main characteristics of such systems is their informal organization of production. The coordination of workflows is done on an ad-hoc basis by means of real-time decisions instead of according to predetermined production plans. Formal scheduling is rarely performed and the sequencing of tasks is continuously adapted in response to changes in workload, time constraints, and availability of input materials. Consequently, several production stages are usually operated in parallel without being strictly synchronized. This informal coordination model was supported by a high proportion of repeat clients, estimated at approximately 75–80%, indicating that operational flexibility did not negatively affect perceived service reliability.

This is closely linked to the fact that process control in these organizations is distributed. Decision-making authority is not located centrally but is divided among employees. Employees decide when components have been prepared sufficiently for them to be moved on to the next stage, whether adjustments are needed, and whether the results of intermediate production stages correspond to their expectations. The transitions between the different stages of production are therefore controlled on an individual basis rather than according to standardized acceptance criteria.

In view of the organizational conditions prevailing in these enterprises, the stage of material preparation does not represent a stage that can be clearly separated from other stages. Sanding and conditioning, for example, are commonly carried out in conjunction with machining and assembly. Moreover, variability in the material condition of products entering the production process, such as variations in moisture content and surface roughness, exists already at the start of production. There are no standard procedures for verifying the consistency of product properties before they undergo further processing.

Machining processes in these enterprises are organized in a hybrid form, i.e., they comprise both digital (i.e., computer-controlled) and manual operations. CNC machinery is used in those cases where identical parts are produced, whereas manual machining is employed for custom parts. The interaction between these two types of operation is not structurally defined. Adjustments resulting from deviations in material behavior or dimensional variation are typically made in subsequent stages of production.

Assembly represents an adaptive and corrective stage. During assembly, components are fitted and aligned on the basis of their actual dimensions and requirements, rather than in accordance with previously specified tolerances. Manual adjustments are frequently necessary. As a consequence of the lack of standardized assembly protocols, variations exist in the methods and sequences employed for assembly, and it is often assembly that corrects the consequences of inconsistencies introduced in preceding stages of production.

Finishing represents both a final stage of production and a location of defect-detection. Surface preparation before the application of finishes is not uniformly standardized. Finishes applied to products depend on the performance of the preceding stages of production and on the environmental conditions existing within the workplace. It is relatively common for finishing products to require rework. Rework is typically handled locally. There are no formal mechanisms in place for providing feedback to earlier stages of production.

Quality control is not established as a formalized or independent system. Rather, quality control is integrated into ongoing production activities. Quality inspections are primarily carried out visually and are concentrated in the latter stages of production. When defects are identified in products, they are corrected via rework. Rework represents the primary mechanism available for correcting errors in products. Standardized measurement or documentation procedures are not uniformly employed.

Material utilization and waste disposal are also not established systematically and coordinated. Waste is generated during cutting, machining, sanding, and rework processes. Material utilization is increased due to repetitive correction processes. Off-cuts and residual materials are handled in an operational manner and do not follow any structured management practices.

The descriptions provided above may be summarized in the following table (See Table 1).

Table 1. Synthesis of Findings

Key Finding	Alignment with Literature	Contradiction / Gap	Implications
Non-linear production workflows with feedback loops	Supports process interdependence [6]	Challenges linear production models (Ratnasingam, 2023)	Need adaptive workflow design
Human-centered decision-making	Consistent with workforce constraints [7]	Underestimated in Industry 4.0 literature	Formalize decision-support systems without removing flexibility
Hybrid CNC and manual processes	Matches hybrid industry structure [13]	Poor integration not addressed in literature	Improve stage integration rather than full automation
Reactive quality control and rework	Supports process dependency theories	Lack of preventive control emphasis	Introduce early-stage quality checks
Waste driven by rework	Aligns with sustainability concerns [5]	Organizational causes underexplored	Reduce waste through process structuring
Limited digital adoption	Matches gradual digitalization trends [17]	Overestimation of tech readiness in literature	Focus on incremental, practical implementation
Informal flexibility (emergent)	Related to flexible systems [2]	Lack of distinction in literature	Shift toward designed flexibility

Source: Compiled by the author.

6. Discussion

6.1. Production Systems as Non-Linear and Adaptive Structures

The results show the production workflow of a small woodworking business is nonlinear and iterative; it has many iterations and loopbacks between stages, for example between finishing and assembling (see Figure 2), to the point at which traditional Production Engineering models cannot be applied due to their assumption of a linear process where each stage can have clear transition points [6; 12].

In practical terms, production in woodworking is typically influenced through ongoing modifications to previously determined production processes. The characteristics of wood and the high degree of customization involved with making furniture make this type of dynamic characteristic a normal part of the process. Due to these factors, the current state-of-the-art for optimizing production, which relies on a stable environment and predictable results, will likely only provide limited value. Therefore, based upon the research findings, woodworking production can best be described as an adaptive system.

Despite the absence of linear workflow structures, the observed system demonstrated the ability to scale, as evidenced by the increase in production volume from 8–12 to 15–20 projects per month.

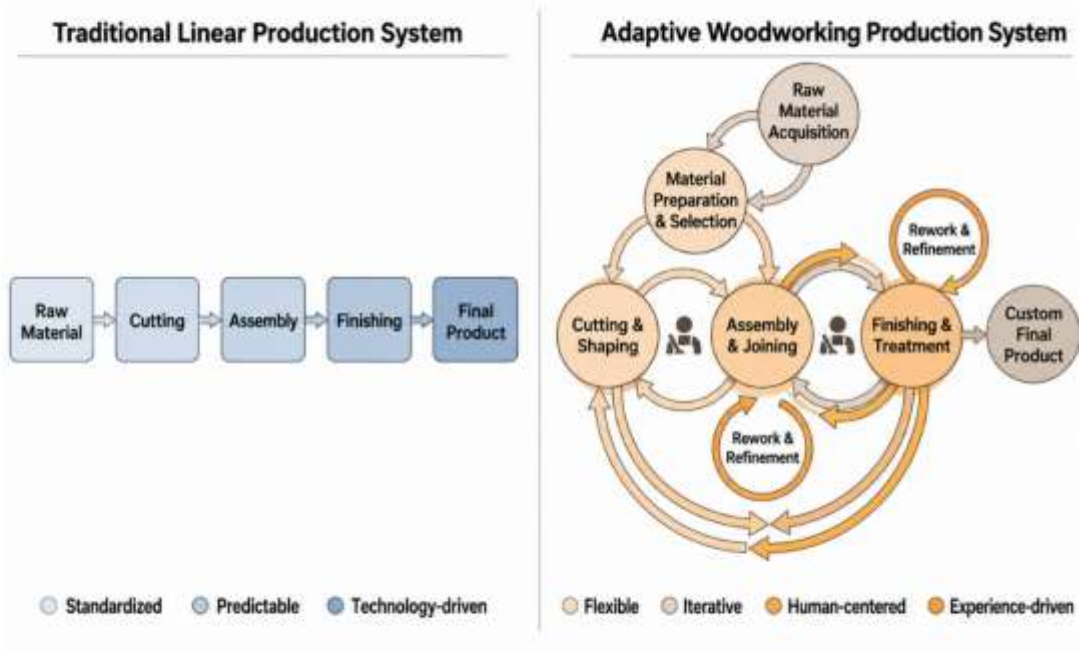

Figure 2. Traditional Linear Production System in the Observed Adaptive Woodworking System

Source: Compiled by the author.

6.2. Human-Centered Decision-Making and Informal Coordination

The findings of this research show that operators' use of their own judgment and discretion in making decisions about what to do next is critical to coordinating the production process. Also important are the ways in which operators rely on their experiences and expertise when determining what to do next. This highlights the importance of the role of tacit knowledge.

Industry 4.0 literature generally supports the idea that greater integration of technology into manufacturing will lead to increased productivity [4; 17]. While the literature also identifies potential barriers related to the workforce [7], the current findings suggest that the way that human judgment and adaptation are used to coordinate is not just a limitation on how efficient an operation can be, but it is actually a primary way that operations are coordinated.

Knowledge transfer played a critical role in stabilizing production processes, with multiple employees being trained in specialized tasks such as staging and quality control, veneer application, precision joinery, and aluminum-glass façade production, allowing these practices to become embedded within daily operations.

These findings demonstrate that small woodworking businesses function as socio-technical systems. In these systems, workers' ability to adapt to changing conditions replaces or supplements the need for formal systems of control. This approach to production provides flexibility and adaptability. However, because these approaches to production are informal, they provide little consistency and may limit the ability to scale.

The importance of human-centered coordination is further reinforced by the role of internal training and skill transfer, which enabled multiple employees to independently manage critical production stages.

6.3. Hybrid Manufacturing: Tension Between Automation and Craftsmanship

The presence of CNC machining alongside manual processes exemplifies the hybrid manufacturing environment found within many woodworking production systems. The differences in both accuracy and finish quality produced using CNC machining versus manual processes reinforce an understanding of the furniture industry as a mix of industrial and craft-based production [13].

This complexity increased further as the company expanded into high-budget custom projects in the range of $250,000–$300,000, requiring tighter tolerances, integration of multiple materials (wood, veneer, aluminum, glass), and more precise coordination between production stages.

The data collected demonstrates that inefficiency arises in woodworking production not because of the hybrid structure, but because of a lack of integration between the automated and manual processes. Therefore, additional resources will be required to develop better integration methods among the various stages of the woodworking production process.

6.4. Quality Control and Defect Propagation

The study identifies defect propagation across production stages as a major source of inefficiency. Imperfections introduced during material preparation or machining become more visible during finishing, leading to rework (See Figure 3).

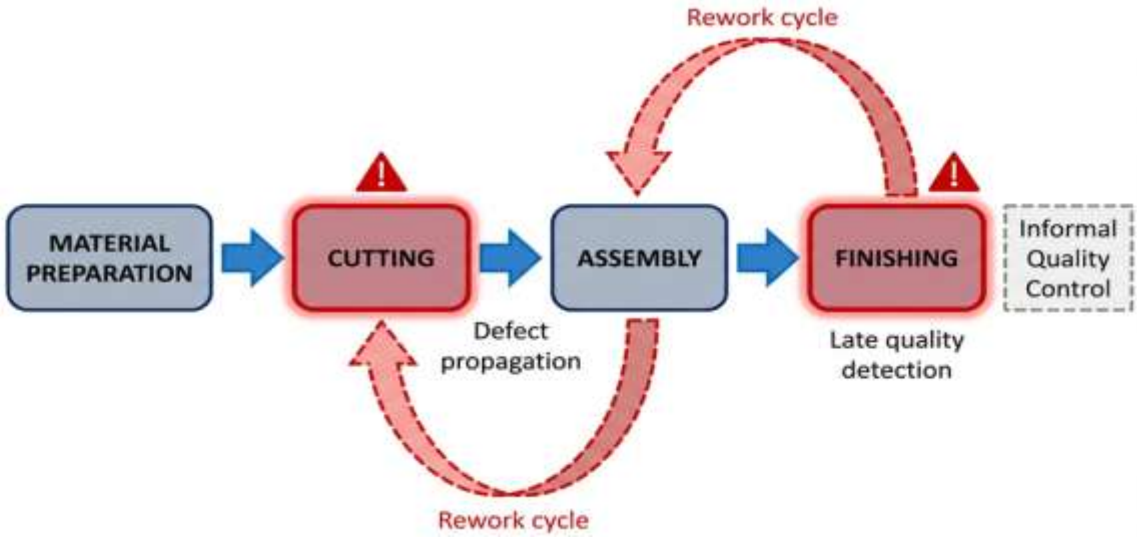

Figure 3. Process Flow with Bottlenecks and Rework Loops

Source: Compiled by the author.

The results support process-based views that emphasize the relationship between the various stages of the production process [6]. However, quality control is primarily reactive as opposed to preventative. Unlike structured production processes that have a quality assurance system integrated into each stage of the production process [12], this research shows that the primary method for controlling quality is through visual inspections and the use of an operator's knowledge.

The measurable reduction in final-stage processing time (from 5–8 hours to 2–3 hours) illustrates how relatively simple organizational interventions can significantly improve efficiency without requiring technological upgrades.

6.5. Organizational Inefficiencies and Sustainability Implications

The data collected show that material waste was directly related to inefficient processes, including rework and a lack of standardization. de Souza Pinho et al. found similar outcomes regarding waste generated during the production of furniture [5]. Awan & Sroufe provided evidence of the need to incorporate circular economic thinking to reduce waste. However, this research extends these previous views by demonstrating that sustainability challenges may be both technological and organizational [1]. By improving the coordination of workflows and decreasing rework, producers can greatly reduce waste with minimal investment in new technology (see Figure 4).

A particularly illustrative example of process improvement was observed in the final inspection and loading stage. Initially, this process required approximately 5–8 hours per project due to unstructured staging and lack of standardized verification procedures. Following the implementation of a structured staging and completeness verification system, processing time was reduced to approximately 2–3 hours per project, representing a 50–60% reduction. This result demonstrates the impact of workflow organization on operational efficiency, independent of technological upgrades.

By improving the coordination of workflows and decreasing rework, producers can significantly reduce material waste and improve operational performance with minimal investment in new technology.

An especially illustrative case of process inefficiency pertained to the final inspection and loading process. At first, this stage took 5–8 hours per project (on about 2,500 sq ft project sizes) because of unstructured staging and insufficient formal completeness checks. After implementation of a structured staging and verification system, the time to completion was then reduced to 2–3 hours, reflecting a 50–

60% reduction in process time. This enhancement allowed same-day delivery upon production completion and decreased delays due to missing or disorganized components.

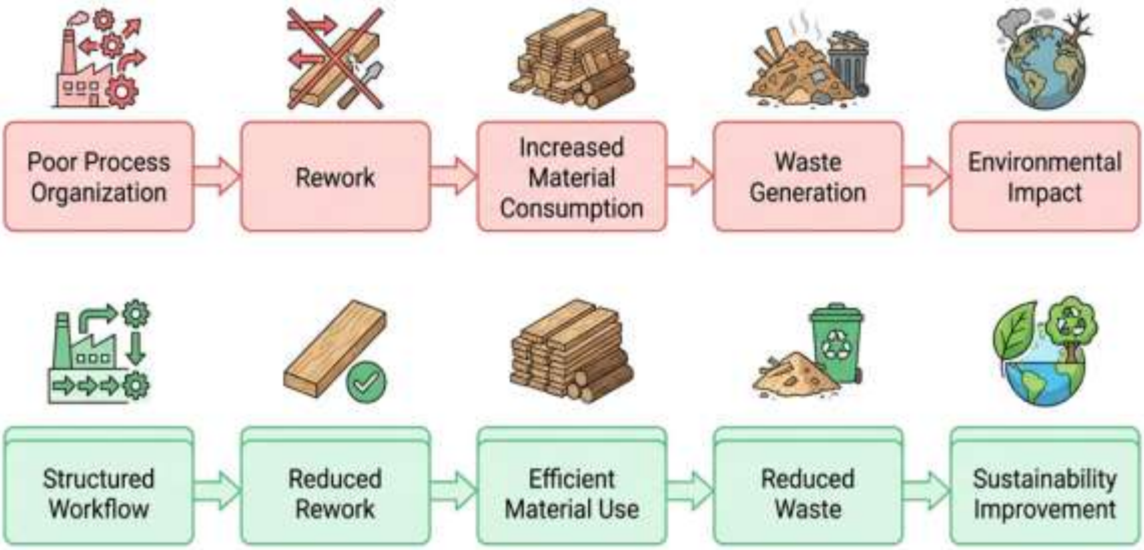

Figure 4. Sustainability Impact Pathway

Source: Compiled by the author.

Although there are various sustainability frameworks available [15; 16], they are still relatively rarely used. In addition to being generally available, these barriers can be explained by the general challenges experienced by SMEs, particularly those related to resources and lack of organized systems [10].

6.6. Digitalization and the Limits of Industry 4.0 Adoption

The research study showed that using digital technologies improved the production flexibility and responsiveness [11]. However, the adoption of digital technologies is varied and selective. For example, CNC technology was adopted only when it provided some operational advantages.

This study's results support the previous research that demonstrated a very low rate of usage of digital technologies in the furniture industry [17]. The study supports the idea that Industry 4.0 will be implemented gradually [4].

In contrast to a total transformation, digitalization of small woodworking companies seems to be an incremental and practical process. The main limitations to digitalization in small woodworking companies are their organizational readiness and workforce capabilities [7].

6.7. Flexibility: Designed vs. Emergent

The concept of flexible manufacturing systems (such as mini-factories) [2] provides a useful theoretical context for understanding the findings. In addition to the flexibility characteristics of closeness to customer and adaptability mentioned above, the studied production environments have several other features of flexibility.

However, while the literature describes flexibility in terms of structured variety, the observed systems represent examples of emergent flexibility. Emergent flexibility is characterized by the use of experiences and informal practices to achieve flexibility.

While this form of flexibility allows for a higher degree of responsiveness, it also causes inefficiency and variation. This distinction between designed flexibility and emergent flexibility represents an important contribution. It shows that bettering organizational structures may lead to better performance without reducing the ability to adapt.

One of the key conceptual contributions of this study is the distinction between emergent flexibility and designed flexibility.

Emergent flexibility refers to the ability of production systems to adapt through informal practices, operator experience, and real-time decision-making. While this form of flexibility enables high responsiveness to variability and customization, it often leads to inconsistency, inefficiency, and increased reliance on rework.

Designed flexibility, in contrast, involves the structuring of workflows, decision points, and process coordination mechanisms in a way that preserves adaptability while reducing variability. Rather than eliminating flexibility, it formalizes it, enabling more predictable outcomes without sacrificing responsiveness.

This distinction provides a framework for understanding how small woodworking businesses can transition from reactive, experience-based operations toward more structured yet flexible production systems. It also highlights that improving performance in such environments does not require full standardization, but rather the intentional design of flexible processes.

This distinction extends existing discussions on flexible manufacturing systems by shifting the focus from technological flexibility to organizational and process-based flexibility.

6.8. Skills, Knowledge, and Process Variability

The findings of the research study show that the skills and knowledge of the operators are essential for managing production variability. Material preparation and finishing are tasks that require a lot of expert knowledge, as was shown in previous studies about wood processing technologies [3].

Therefore, variability in production outcomes depends not only on the design of the production systems, but also on human abilities. Therefore, training and knowledge transfer should be considered as the most important components for optimizing production.

6.9. Theoretical and Practical Implications

This research study makes an important contribution to the literature by showing that production systems of small woodworking companies are complex organizations, and not less developed from a technical point of view. As prior research focused on the development of new technologies, the findings of this study show that the coordination of production processes and human coordination are the most important factors.

Therefore, the key implication is that improvement of the efficiency and sustainability of small woodworking companies should focus on structuring of the workflow, integration of different production stages and formalization of the quality control processes, and not only on the upgrade of the technologies.

Finally, the study demonstrates that process organization is the most important factor for increasing the efficiency, quality and sustainability of the small woodworking companies. As the study bridges the gap between theoretical models and real-world practices, it calls for more integrated approaches combining the technological tools with human-centered and organizational strategies (see Table 2).

Table 2. Study Contributions

Contribution Area	What This Study Shows	How It Extends Literature
Production Structure	Workflows are non-linear and iterative	Challenges linear production models [6; 12]
Role of Humans	Decision-making is decentralized and experience-based	Extends Industry 4.0 discussions beyond technology [7]
Manufacturing Model	Hybrid system (CNC + manual) dominates	Supports but deepens hybrid production literature [13]
Quality Control	Reactive rather than preventive	Identifies gap in small-scale production systems
Sustainability	Waste driven by rework and inefficiency	Links operations directly to sustainability [1]
Digitalization	Incremental and selective adoption	Confirms slow Industry 4.0 transition [17]
Flexibility Concept	Emergent (informal) vs designed flexibility	Introduces new conceptual distinction
Key Insight	Organization > Technology for performance	Reframes dominant perspective in literature

Source: Compiled by the author.

The execution of upscale residential projects, including a custom project worth about $295,000 that was finished in two months, further demonstrates the potential of such structured yet flexible systems. The effective integration of intricate components like precision installation, custom joinery, and aluminum-glass facades emphasises the significance of quality control and final-stage coordination in attaining premium-level results.

7. Conclusions

This study aimed to investigate the production processes in small woodworking businesses in terms of the organization of workflows, efficiency and sustainability. The results indicate that production systems of such nature cannot be analyzed based on the traditional models of linear flow or technology-oriented models. Rather, they represent adaptive, man-centered, and organizationally complex systems where their performance depends mainly on the coordination practice of the operators involved, rather than the capabilities of the technologies used.

One of the conclusions of the study is that the causes of the process inefficiencies lie more in the poor structuring and integration of workflows than in the lack of technology. The studied non-linear production flows, many cycles of rework, and the local decision-making show clearly the limits of application of the conventional production engineering models [6; 12] to small-scale customized manufacturing environments. These models advocate predictability and control, whereas the reality of woodworking production is characterized by variability, iteration and continuous adjustments.

The study also highlights the importance of human expertise and tacit knowledge. It is the operator who acts as the main coordinator of the production and who makes decisions in real time, allowing them to respond quickly to variations. This finding contradicts the majority of Industry 4.0 narratives that advocate for automation and digitalization [4], and suggests that human-centered systems are essential for the operation of small-scale manufacturing companies. Nevertheless, the use of informal coordination creates inconsistency, which prevents the achievement of efficiency and scalability.

Finally, the study underlines the hybrid nature of the production systems, characterized by the coexistence of CNC-based precision and manual craftsmanship. Although this association allows the realization of customization and adaptability, the inefficiency of the production process stems from the lack of integration between these two phases. Therefore, there is a need for greater synchronization rather than total automation, reinforcing the thesis according to which technological adoption should be adapted to the context and progressive [7; 17].

In terms of sustainable development, the study shows that material waste is strongly correlated to the inefficiencies of the organizations, especially rework and reactive quality control. Although the existing literature focuses on recycling and circular economy [1; 5], the study shows that important environmental gains could be obtained by organizing the process better. This reframes sustainability as not only a technological or strategic problem but also an operational one.

The study contributes to the literature by highlighting the difference between emergent flexibility and designed flexibility. Small woodworking companies have a high level of adaptability; however, this flexibility is often informal and experience-based. Transforming it into structured, systematic flexibility is therefore a key way to improve efficiency while maintaining the ability to respond.

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