GOCE DELCEV
UNIVERSITY
FACULTY OF NATURAL AND
TECHNICAL SCIENCES

NATURAL RESOURCES AND TECHNOLOGY

Online ISSN 1857-8829
Print ISSN 1857-6966
DOI: 10.46763/NRT

No 1 Volume XX

JUNE 2026

GOCE DELCEV UNIVERSITY – STIP
FACULTY OF NATURAL AND TECHNICAL SCIENCES

Natural Resources and Technology

JUNE 2026

VOLUME: XX **NO. 1**

Online ISSN 1857-8829 **Print ISSN 1857-6966**

NATURAL RESOURCES AND TECHNOLOGY

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Manuscript received: 17.03.2026
Accepted: 24.04.2026

Natural Resources and Technology
Vol 20, No. 1, pp.27 - 36 (2026)
Online ISSN 1857-8829; Print ISSN 1857-6966
DOI: https://doi.org/10.46763/NRT2620127k
Original scientific papers

MATERIAL UTILIZATION EFFICIENCY IN PANEL CUTTING FOR FURNITURE MANUFACTURING: COMPARATIVE EVALUATION OF CONVENTIONAL AND INTEGRATED CAD-CAM OPTIMIZATION SYSTEMS

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Abstract

Efficient material utilization in panel cutting is a critical factor for cost reduction and sustainability in custom furniture manufacturing. This study presents a comparative evaluation of material utilization efficiency under three different cutting preparation approaches: (1) conventional manual dimension input using Optimik software, (2) digital 3D parametric modeling with Corpus software and (3) fully integrated optimization combining Corpus with the machine-specific Ardis Optimizer.

The research was conducted under real production conditions at a custom panel furniture manufacturer. Nineteen furniture pieces of varying structural complexity were analyzed for a production batch of 100 identical units each. Material utilization was measured as the absolute percentage of panel area converted into final components, using standardized particleboard.

Results showed that the integrated Corpus + Ardis approach consistently achieved the highest material utilization rates (often 90–95%) and required the fewest panels for most items, outperforming both the conventional Optimik method and the standalone Corpus software. The greatest improvements were observed in complex products such as wardrobes, kitchen cabinets and office furniture. The findings demonstrate that full synchronization between CAD/CAM design software and CNC machine parameters significantly enhances nesting efficiency and reduces material waste. This study provides practical evidence supporting the adoption of integrated CAD-CAM systems in the furniture industry. Recommendations for implementation and directions for future research are discussed.

Key words: *material utilization, panel cutting optimization, nesting, CAD-CAM integration, furniture manufacturing, cutting stock problem, waste reduction*.

INTRODUCTION

Efficient utilization of panel materials is considered a critical economic factor in contemporary furniture manufacturing, particularly in the production of custom cabinet systems. In panel-based furniture production, materials such as particleboard, medium-density fiberboard (MDF) and plywood account for a substantial proportion of total production costs [1]. Even minor improvement in cutting optimization can therefore generate significant financial savings at the industrial scale. At the same time, material waste generated during panel cutting contributes to increased resource consumption, additional handling costs, and environmental burden [2]. Reducing waste is thus not only an economic necessity but also an important component of sustainable manufacturing practices within the wood-processing sector [3].

Traditional panel cutting preparation has often relied on manual layout planning and operator experience. While such approaches may provide acceptable results for simple component structures, they are typically limited in their ability to achieve optimal nesting efficiency, particularly in complex custom furniture configurations [4]. The increasing demand for made-to-measure cabinet systems, characterized by dimensional variability and high component diversity, further highlights the need for advanced digital optimization tools.

The integration of computer-aided designs (CAD) and computer-aided manufacturing (CAM) technologies have transformed production preparation processes in the furniture industry [6]. Specialized software solutions enable digital generation of component layouts and automated nesting

strategies, improving accuracy and reducing preparation time compared to conventional methods [7]. However, the optimization performance of standalone CAD systems may remain constrained when not entirely synchronized with machine-specific parameters applied during the actual cutting phase.

Advanced integration between design software and machine-level optimization platforms introduces an additional layer of operational precision. By incorporating machine characteristics – including cutting kerf width, saw blade thickness, tool diameter and other production constraints-integrated CAD-CAM workflows allow nesting algorithms to generate layouts that closely align with real production conditions [8]. Such synchronization reduces discrepancies between digital planning and actual execution, potentially minimizing material waste and increasing overall material utilization efficiency [9].

Despite the growing adoption of digital systems in furniture manufacturing, empirical industrial studies that quantitatively compare conventional, standalone CAD and fully integrated CAD-CAM cutting preparation approaches remain limited [10]. Existing research focuses on algorithm development rather than real production data obtained under controlled industrial conditions. Therefore, a systematic comparative evaluation of material utilization across different technological workflows is needed.

The aim of this study is to evaluate material utilization efficiency in panel cutting for custom cabinet furniture production across three preparation approaches:

- Conventional cutting preparation with manually defined layouts processed in Optimik
- Digital nesting generated in Corpus and
- Integrated machine-level optimization using Ardis under actual production conditions

Material utilization is assessed as the ratio between the total area of cut components and the total board area used, expressed as a percentage. The study seeks to determine whether integrated CAD-CAM synchronization with machine specific parameters results in significant improvements in material efficiency.

MATERIAL AND METHODS

The research was conducted under real production conditions at Drvodekor Enterier, a company specializing in custom-made panel furniture, located in Stip, Macedonia. Nineteen furniture pieces of varying structural complexity were selected for analysis (Figure 1). Note that Element N.4 (TV Unit) was planned in two color particleboards, therefore the results include data for 20 items. The study focuses exclusively in the preparatory phase of production. The operational phase (actual physical cutting and assembly) was not included.

For each furniture piece, cutting layouts were generated and material utilization data were collected for a production batch of 100 identical units. The selected materials, consistent with the conceptual design shown in Figures 1 and 2, comprised particleboard (chipboard) panels measuring 2800x2070mm in thickness of 16mm, 18mm and 25mm and medium-density fiberboard (MDF) measuring 2800x20270x18mm.

Material utilization was evaluated using three methodological approaches that represent increasing levels of digital integration:

- Conventional approach (Optimik): Element dimensions were manually defined by the designer based on technical drawings prepared in AutoCAD (Figure 2). The dimensions were organized in a tabular form and entered manually into the Optimik software (version 2.17), developed by Rastislav Korytar (Slovakia, 1999-2002) [11]. This approach simulates traditional workflow relying on operator experience and manual data input.
- Digital approach (Corpus): All nineteen elements were modeled as three-dimensional parametric components within the Corpus 5.0 software [12]. Based on these models, the software automatically generated cutting layouts and production data, presented in Table 2.
- Integrated approach (Corpus + Ardis): Production data generated in Corpus were exported and further optimized using the Ardis Optimizer [13], the machine-specific cutting optimization software integrated with horizontal CNC panel saw at Drvodekor Enterier. This approach incorporates real machine parameters for final nesting.



Figure 1. Conceptual design – 3D models / Perspective of all furniture pieces subject to the research, created using the visualization software SketchUp + V-ray

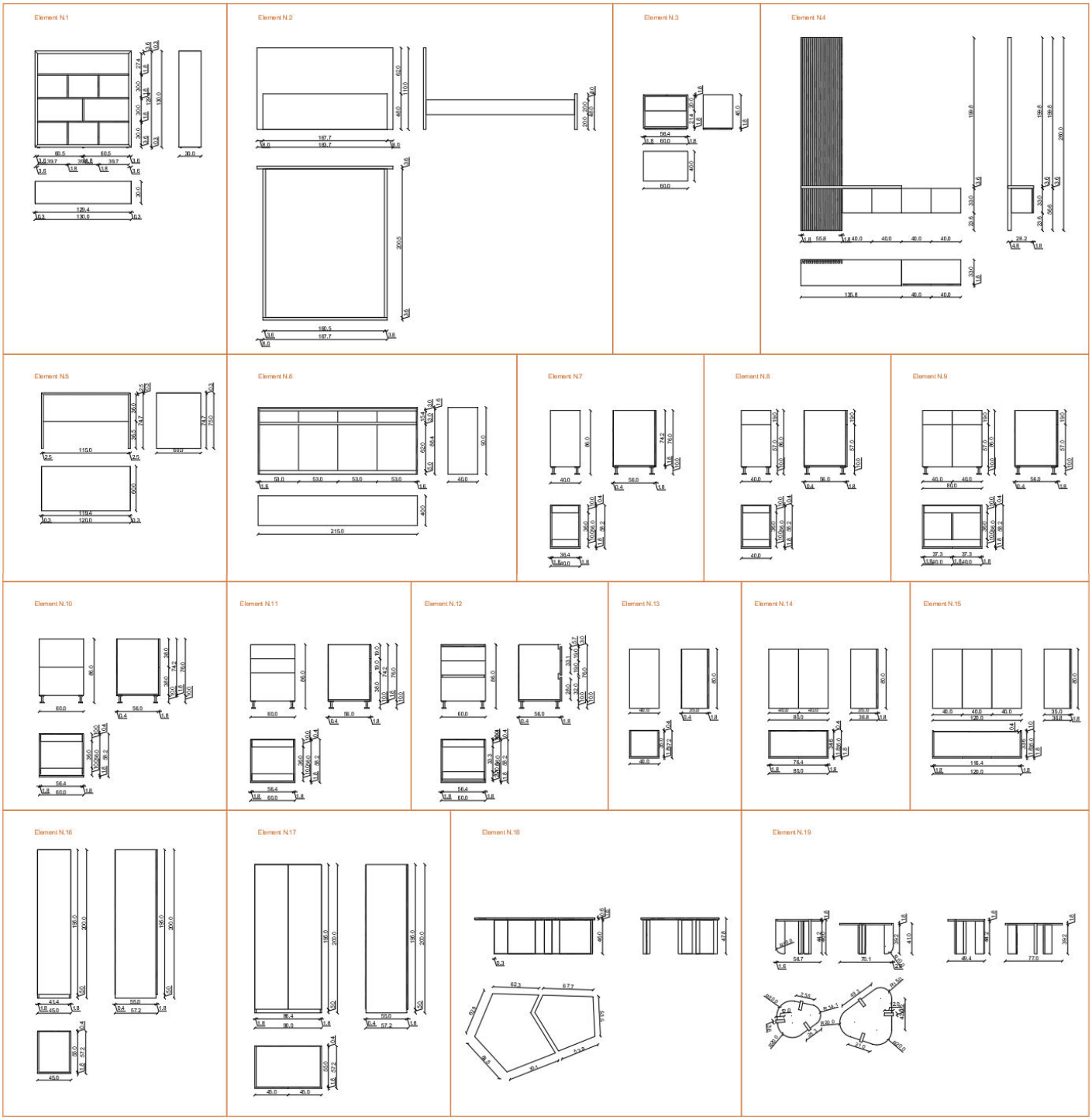


Figure 2. Orthogonal projection / 2D models with dimensions of all furniture pieces subject to the research, created using AutoCAD

Consistent technological parameters were applied across all approaches to ensure comparability. The kerf (cutting width) was set to 4.4mm in Optimik and Corpus, and 4.5mm in Ardis, reflecting actual machine characteristics. Edge trimming was uniformly set to 10mm on all panel sides to account for machining tolerances and to produce clean final edges.

Material utilization efficiency was calculated as the ratio of the total area of components incorporated into the final furniture pieces to the total area of panels used, expressed as a percentage (absolute material utilization). Reusable offcuts were distinguished from irreversible waste.

Table 1. Material utilization during production preparation using the conventional method with the Optimik software

N.	FURNITURE		MATERIAL UTILIZATION FOR 100 PIECES OF FURNITURE IN **OPTIMIC**									
			Used panels (N)	Used panels area (m2)	Cut pieces (N)	Cut pieces area (m2)	Usable waste in pieces (N)	Usable waste area (m2)	Waste area (m2)	Cutting length (m2)	Relative material utilization (%)	Absolute material utilization (%)
1	EL N.1	FREE-STANDING SHELF	100	572,68	1600	456,426	176	98,86	17,396	2085,08	96,96	79,7
2	EL N.2	DOUBLE SIZE BED	240	1379,37	800	703,24	440	651,48	24,66	2090,1	98,21	50,98
3	EL N.3	NIGHT STAND	29	166,077	1000	153,641	10	5,22	7,213	791,22	95,66	92,51
4	EL N.4	TV UNIT (decor 1)	72	413,813	3500	358,999	66	28,88	25,94	4855,832	93,73	86,75
5	EL N.4	TV UNIT (decor 2)	45	258,633	1100	235,612	44	11,637	11,38	1116,78	95,6	91,1
6	EL N.5	WORK DESK	40	229,072	400	199,742	80	20,825	8,505	645,29	96,29	87,2
7	EL N.6	OFFICE CABINET	146	836,113	4000	788,515	53	11,04	36,56	4409,4	95,63	94,31
8	EL N.7	KITCHEN BASE CABINET	35	201,159	700	162,802	49	32,81	5,54	688,53	97,24	80,93
9	EL N.8	KITCHEN BASE CABINET	36	206,906	1200	196,978	1	2,04	7,891	964,77	96,19	95,2
10	EL N.9	KITCHEN BASE CABINET	66	379,328	2200	360,85	1	4,174	14,304	1842,54	96,23	95,13
11	EL N.10	KITCHEN BASE CABINET	56	321,85	1700	305,555	2	3,18	13,12	1496,31	95,92	94,94
12	EL N.11	KITCHEN BASE CABINET	63	362,086	2300	345,901	1	1,82	14,362	1868,07	96,03	95,53
13	EL N.12	KITCHEN BASE CABINET	61	350,591	2300	334,143	1	2,81	13,635	1862,46	96,11	95,31
14	EL N.13	KITCHEN HANGING CABINET	28	160,927	700	137,805	28	18,015	5,107	630,681	96,83	85,63
15	EL N.14	KITCHEN HANGING CABINET	45	258,633	800	224,035	71	26,312	8,285	936,822	96,8	86,62
16	EL N.15	KITCHEN HANGING CABINET	62	356,339	1100	321,103	47	21,078	14,16	1317,92	96,03	90,11
17	EL N.16	WARDROBE	84	482,782	1000	445,92	57	19,24	17,62	1394,41	96,35	92,36
18	EL N.17	WARDROBE	111	637,961	900	590,999	80	22,19	24,774	1664,32	96,12	92,64
19	EL N.18	COFFEE TABLES	30	171,804	1400	162,42	1	1,318	8,07	990,84	95,3	94,54
20	EL N.19	COFFEE TABLES	60	343,608	200	178,19	140	162,59	2,825	409,84	99,18	57,42

Table 2. Material utilization during production preparation using the specialized software Corpus

N.	FURNITURE		MATERIAL UTILIZATION FOR 100 PIECES OF FURNITURE IN **CORPUS**									
			Used panels (N)	Used panels area (m2)	Cut pieces (N)	Cut pieces area (m2)	Usable waste in pieces (N)	Usable waste area (m2)	Waste area (m2)	Cutting area (m2)	Cutting length (m)	Absolute material utilization (%)
1	EL N.1	FREE-STANDING SHELF	99	573,804	1600	461,93	245	98	0,75	13,27	3016,78	80,5
2	EL N.2	DOUBLE SIZE BED	250	1449	800	706,65	638	711,65	\	20,53	4666,63	48,77
3	EL N.3	NIGHT STAND	29	168,084	1000	155,7	57	5,37	2,67	4,93	1119,45	92,63
4	EL N.4	TV UNIT (decor 1)	80	463,68	3600	375,98	434	65,34	5,38	27,17	6174,6	81,09
5	EL N.4	TV UNIT (decor 2)	52	301,392	1100	238,61	129	51,54	3,98	7,35	1670,55	79,17
6	EL N.5	WORK DESK	45	260,82	400	201,16	123	52,45	1,39	4,79	1090,77	77,13
7	EL N.6	OFFICE CABINET	150	869,4	4100	804,14	678	25	13,6	28,16	6399,11	92,49
8	EL N.7	KITCHEN BASE CABINET	34	197,064	700	163,69	120	27,23	1,28	4,58	1041,99	83,06
9	EL N.8	KITCHEN BASE CABINET	37	214,452	1200	195,35	124	11,33	2,16	6,03	1370,95	91,09
10	EL N.9	KITCHEN BASE CABINET	66	382,536	2000	349,03	163	19,99	3,83	10,63	2416,99	91,24
11	EL N.10	KITCHEN BASE CABINET	57	330,372	1500	301,45	152	18,32	2,34	8,67	1972,23	91,25
12	EL N.11	KITCHEN BASE CABINET	62	359,352	2000	328,52	195	19,41	2,23	40,43	2370,18	91,42
13	EL N.12	KITCHEN BASE CABINET	59	341,96	2000	316,39	143	14,05	2,78	10,18	2313,9	92,52
14	EL N.13	KITCHEN HANGING CAB	28	162,288	700	138,69	41	18,3	1,44	4,06	922,72	85,46
15	EL N.14	KITCHEN HANGING CAB	48	278,21	800	224,8	139	44,48	2,33	6,35	1442,87	80,8
16	EL N.15	KITCHEN HANGING CAB	63	365,148	1200	332,71	137	20,44	3,19	8,94	2031,71	91,12
17	EL N.16	WARDROBE	107	620,172	1100	466,88	272	137,72	1,69	11,39	2588,32	75,28
18	EL N.17	WARDROBE	155	898,38	900	588,44	338	290,39	0,71	14,42	3276,76	65,5
19	EL N.18	COFFEE TABLES	33	191,26	1400	166,39	100	15,09	4,32	5,99	1361,23	86,99
20	EL N.19	COFFEE TABLES	66	382,536	200	176,15	134	198,8	\	4,61	1048,53	46,05

Table 3. Material utilization during production preparation using the specialized software Corpus and the Ardis optimizer

N.	FURNITURE		MATERIAL UTILIZATION FOR 100 PIECES OF FURNITURE IN ARDIS + CORPUS	
			Used panels (N)	Absolute material utilization (%)
1	EL N.1	FREE-STANDING SHELF	91	86,54
2	EL N.2	DOUBLE SIZE BED	200	60,67
3	EL N.3	NIGHT STAND	28	94,67
4	EL N.4	TV UNIT (decor 1)	72	86,68
5	EL N.4	TV UNIT (decor 2)	44	92,43
6	EL N.5	WORK DESK	41	84,05
7	EL N.6	OFFICE CABINET	145	94,56
8	EL N.7	KITCHEN BASE CABINET	30	93,24
9	EL N.8	KITCHEN BASE CABINET	36	92,49
10	EL N.9	KITCHEN BASE CABINET	64	92,92
11	EL N.10	KITCHEN BASE CABINET	55	93,47
12	EL N.11	KITCHEN BASE CABINET	60	93,18
13	EL N.12	KITCHEN BASE CABINET	57	94,43
14	EL N.13	KITCHEN HANGING CABINET	27	87,55
15	EL N.14	KITCHEN HANGING CABINET	43	89,26
16	EL N.15	KITCHEN HANGING CABINET	60	94,69
17	EL N.16	WARDROBE	88	90,91
18	EL N.17	WARDROBE	110	91,67
19	EL N.18	COFFEE TABLES	31	91,33
20	EL N.19	COFFEE TABLES	50	60,57

RESULTS

The material utilization efficiency during technological preparation for custom panel furniture production was assessed using three optimization approaches: the integrated Corpus + Ardis workflow, the standalone Corpus optimizer, and the dedicated cutlist optimizer Optimik. The analysis covered 19 individual furniture elements (EL N.1 to EL N.19), with all results scaled to a production batch of 100 identical units. Two key performance indicators were evaluated: (1) the total number of raw boards (panels) consumed, and (2) the absolute material utilization rate (%), which accounts exclusively for the material incorporated into the final furniture components, excluding reusable offcuts. Fig. 3 shows the number of boards utilized by each method across the 19 elements.

The Corpus + Ardis integrated approach recorded the lowest board consumption in the majority of cases. Particularly large differences were observed for more demanding elements, such as EL N.2 (where Corpus + Ardis used noticeably fewer boards than both alternatives). The standalone Corpus optimizer consistently required the highest number of boards across nearly all elements, often exceeding the other methods by a substantial margin.

Optimik performed between the two, achieving results comparable to or occasionally slightly better than Corpus + Ardis on several elements (e.g., EL N.6, EL N.17, EL N.19), but the differences were generally small.

Fig. 4 presents the absolute material utilization percentages of the consumed boards. In this indicator, the results were more evenly distributed. Corpus + Ardis achieved the highest utilization rate in approximately half of the elements, while Optimik performed better in the remaining cases. The standalone Corpus optimizer again showed the lowest utilization percentages in most instances. When Optimik recorded a higher percentage than Corpus + Ardis, the difference ranged from a minimal 0.07% to a maximum of 3.21%. Conversely, in cases where Corpus + Ardis outperformed Optimik, the improvement reached up to 12.31%.

In the conventional approach, using manual dimensions input into Optimik software, the absolute material utilization ranged widely from 50.98% (bed) to 95.53% (kitchen base cabinets), with an overall average around 85-90% for most items (16 items).

The digital approach with the Corpus software generated automatic layouts based on 3D parametric modeling, which reduced manual input errors but did not always account for machine-specific cutting constraints.

The integrated approach (Corpus data exported to Ardis Optimizer) delivered the most consistent and generally superior results. Absolute material utilization reached 93-94% for many elements. The number of panels required was often lower compared to the conventional and standalone Corpus approaches. Ardis, being directly linked to the CNC horizontal panel saw parameters, produced layouts better aligned with actual production conditions.

The results clearly indicate that the choice of software approach for cutting optimization has a substantial impact on material utilization efficiency in the production of made-to-order panel furniture.

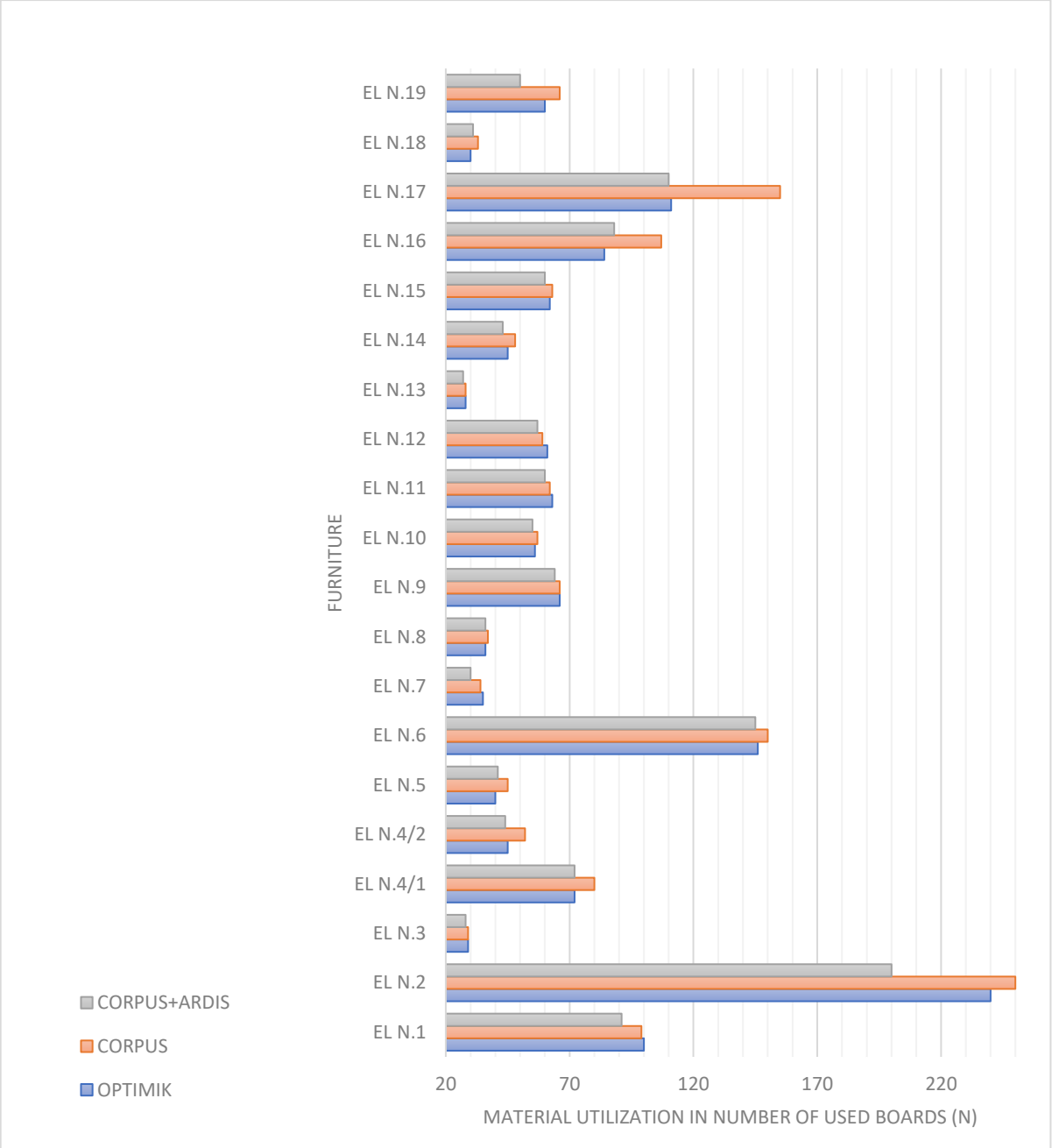


Figure 3. Comparison of the number of panels (boards) used for the production of 100 units of each furniture piece across the three optimization approaches.

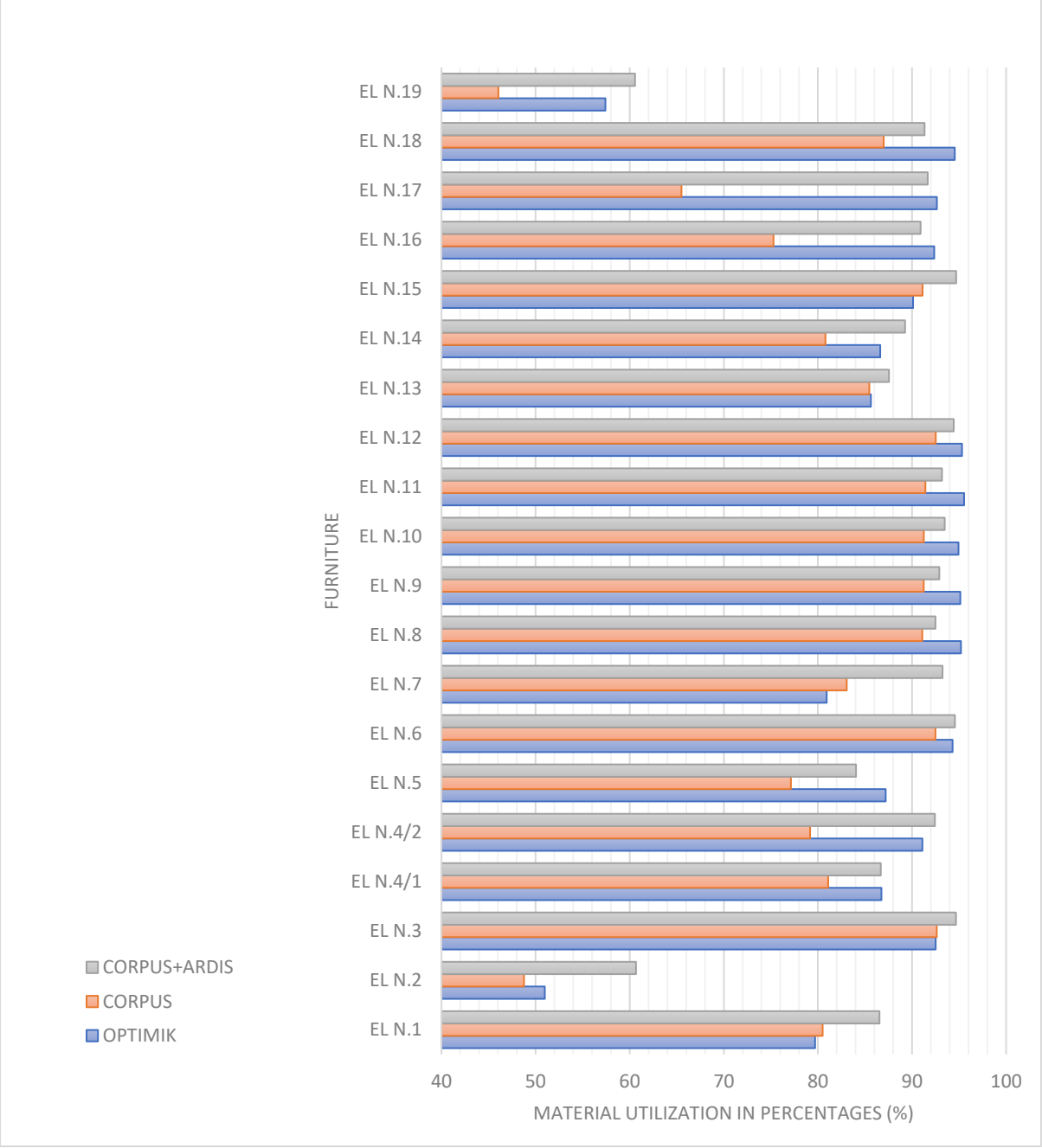


Figure 4. Absolute material utilization percentage achieved for each furniture piece under the three preparation methods (Optimik, Corpus and Corpus+Ardis)

DISCUSSION

The integrated Corpus + Ardis workflow consistently delivered the most favorable outcomes by minimizing the total number of boards required while maintaining competitive or superior utilization rates on the consumed material. This dual advantage is particularly evident in larger or geometrically complex elements (e.g., EL N.1, EL N.2, EL N.7, and EL N.20), where reductions of 5–10 or more boards compared to the standalone Corpus optimizer were observed. Such savings carry significant economic weight in micro-enterprises, where material costs represent a major portion of production expenses and batch sizes are often small and variable.

The more balanced performance in absolute utilization percentage (Fig. 4) between Corpus + Ardis and Optimik must be interpreted in conjunction with the board-count data (Fig. 3). Although

Optimik occasionally achieved slightly higher percentages (up to 3.21% better), these gains occurred on a higher or comparable number of boards. In contrast, Corpus + Ardis frequently reduced overall board consumption while achieving utilization improvements of up to 12.31% in several cases. This combination results in superior actual production efficiency, as the absolute material waste is lower when fewer boards are processed in total. The distinction between theoretical nesting yield and real-world consumption (excluding reusable offcuts) underscores the practical value of the evaluated indicators.

The superior performance of Corpus + Ardis stems from the seamless digital integration between the parametric design environment (Corpus) and the advanced, machine-oriented cutting optimizer (Ardis). Ardis is a professional modular platform developed specifically for the sheet cutting industry, offering precise configuration of technological parameters such as kerf width, grain direction, trim cuts, cutting sequence, remnant priorities, and direct integration with various panel saws and nesting machines. This machine-specific tailoring enables more realistic and efficient nesting patterns than those generated by general-purpose tools or built-in optimizers.

Optimik, a well-established all-in-one cutlist optimizer with strong layout algorithms and production planning features, performed reliably and often competitively, particularly on smaller elements. However, it lacks the same depth of direct, machine-parameter integration in this workflow, which appears to limit its ability to consistently outperform the integrated approach on complex parts.

The standalone Corpus optimizer, being a built-in module within the design software, showed the weakest results in every case analyzed. This highlights the limitations of non-specialized or insufficiently configurable optimization tools that do not fully account for the technological constraints and capabilities of modern CNC panel saws.

These findings align with the broader need for comprehensive CAD–CAM integration in custom furniture manufacturing. By linking design data directly to a machine-tailored optimizer, manufacturers can achieve meaningful reductions in material consumption, lower production costs, and improved process control — benefits that are especially critical for micro-enterprises operating in a made-to-order environment. Beyond direct material savings, such integration enhances technological readiness, reduces planning errors and supports more sustainable production practices through minimized waste.

Limitations of the present study include its focus on a specific set of 19 elements and a fixed batch size of 100 units. Actual gains may vary with different panel dimensions, material types (e.g., chipboard or MDF), machine configurations, and remnant management strategies. Future research could extend the analysis to a wider product range, incorporate multi-objective optimization (balancing material use with cutting time and labor) and evaluate long-term economic and environmental impacts under industrial workshop conditions.

Limitations of this study include its focus on the preparatory phase only and the data collected from a single manufacturing facility. Future research should investigate the long-term economic and ecological benefits of integrated systems across multiple production runs and different company sizes.

In summary, the integrated Corpus + Ardis approach provided the most consistent and economically justified results. The study confirms the strategic importance of using specialized, machine-configured optimization tools within a fully digital workflow for enhancing material efficiency and competitiveness in custom panel furniture production.

CONCLUSION AND RECOMMENDATIONS

This study evaluated material utilization efficiency in panel cutting for custom cabinet furniture production by comparing three preparation approaches: conventional manual input using Optimik, digital modeling with Corpus and fully integrated optimization using Corpus combined with Ardis. The results demonstrated that the integrated CAD-CAM approach (Corpus + Ardis) consistently achieved the highest absolute material utilization rates and required the lowest number of panels for the majority of the 19 tested furniture pieces. These improvements were particularly evident in complex items such as wardrobes, kitchen cabinets and office furniture, confirming that synchronization between design software and machine-specific parameters significantly enhances nesting efficiency and reduces material waste. The findings highlight that moving from conventional heuristic-based planning to fully integrated CAD-CAM systems can deliver measurable gains in material efficiency under real production conditions. While the standalone Corpus software offered improvements over traditional methods, the greatest benefits were realized only when digital layouts were further optimized at the

machine level. This underscores the importance of seamless integration between CAD, CAM and CNC equipment in modern furniture manufacturing.

Based on the results, custom furniture manufacturers are strongly encouraged to adopt integrated CAD-CAM optimization systems, particularly those that incorporate real machine parameters such as kerf width and cutting tool characteristics. Companies currently relying on manual or semi-automated processes should consider gradual implementation of integrated solutions to reduce raw material consumption, lower production costs, and improve sustainability performance. For optimal results, manufacturers should ensure proper training of technical staff, maintain consistent parameter settings across software platforms, and regularly update optimization tools to match their specific CNC machinery. Future research should expand this comparative analysis to a larger number of companies, incorporate the impact of remnant reuse strategies across multiple production batches, and evaluate the long-term economic and environmental benefits of integrated systems. Additionally, studies examining the relationship between product complexity and optimization effectiveness would provide valuable guidance for tailoring digital tools to different segments of the furniture industry.

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