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Analysis of Woven Fabric Structure from Integrated Countershaft Shedding Mechanism on an Indigenous Handloom

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Abstract

Purpose: This study examines the integration of a countershaft shedding mechanism into indigenous Ghanaian handlooms as a means of enhancing fabric mechanical performance, structural quality, and design complexity while maintaining cultural authenticity. Specifically, it evaluates how improved shedding control influences tensile behaviour, drape characteristics, pattern accuracy, and weaver experience when compared with conventional two-heddle handloom systems.

Methodology/Design: A mixed-methods research design was employed, combining experimental fabric production, mechanical testing, and qualitative artisan evaluation. An indigenous four-post handloom was modified with a countershaft shedding system and used to produce woven fabrics across multiple shaft configurations (four to six shafts), including plain derivatives, twills, diamonds, and satin structures. Quantitative tensile strength tests were conducted in both vertical (warp-dominated) and horizontal (weft-dominated) directions, alongside manual and instrumental assessments of drape and structural integrity. Qualitative data were collected through surveys and expert evaluations involving master weavers from Bonwire and Agortime-Kpetoe, focusing on usability, ergonomic impact, pattern precision, and perceived fabric quality.

Findings: Results demonstrate that countershaft-woven fabrics exhibit improved warp-direction tensile efficiency, enhanced stiffness control at operational strain levels, and superior drape compared to conventional handloom fabrics. Multi-shaft weave structures showed clearer motif definition, reduced yarn slippage, and more uniform interlacement. Artisans reported significantly reduced physical strain, increased weaving speed, and expanded creative freedom, enabling efficient production of complex weave structures such as straight, pointed, and diamond twills that are impractical on traditional looms.

Practical and Social Implications: The countershaft shedding mechanism offers a scalable and culturally sensitive pathway for upgrading indigenous handloom technology. By improving fabric quality, reducing physical labour, and enabling higher-value textile products, the system enhances artisan productivity, market competitiveness, and occupational sustainability while preserving traditional weaving knowledge and aesthetics.

Originality: This study provides one of the first integrated empirical evaluations of countershaft shedding mechanisms within indigenous handloom contexts, combining mechanical fabric analysis with practitioner-centred qualitative insights. It advances a sustainable model for handloom innovation that aligns technological enhancement with cultural continuity, positioning indigenous handwoven textiles as structurally reliable and commercially competitive in contemporary markets.

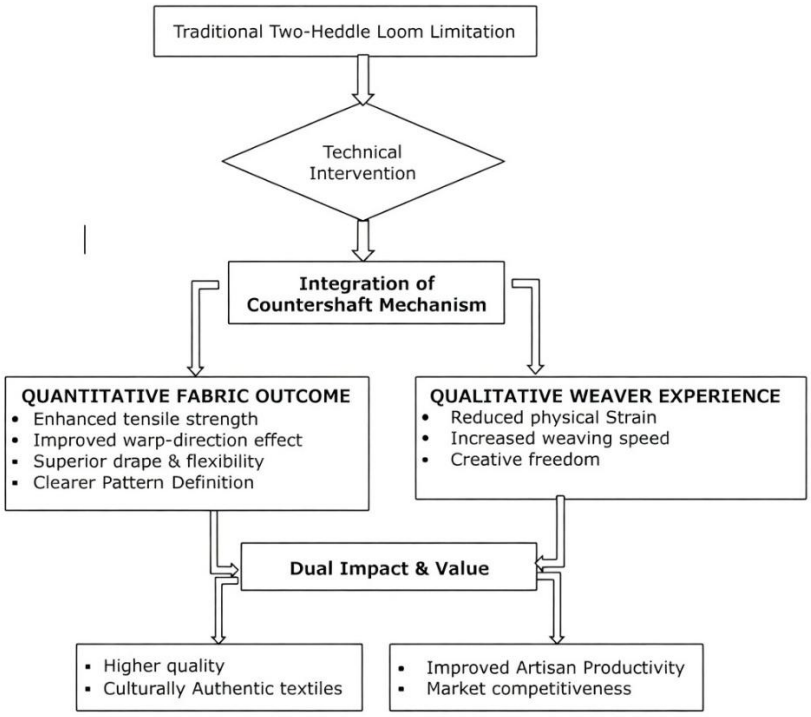
Keywords
Countershaft shedding mechanism, mixed-methods textile research, tensile behaviour, fabric drape, indigenous handlooms, cultural sustainability, handloom innovation

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Graphical Abstract



1 | INTRODUCTION

Clothing Indigenous handloom weaving represents one of the most enduring textile production traditions in the world. Beyond their functional role, handwoven textiles embody cultural memory, social identity, and indigenous knowledge systems that have been transmitted across generations. In many societies, particularly in Africa and Asia, handloom fabrics continue to function as markers of status, ritual significance, and artistic expression while sustaining rural economies through low-energy and labour-intensive modes of production (Ingold, 2000; Roy Maulik, 2021). In Ghana, indigenous handwoven textiles occupy a central place within cultural life. Narrow strip woven fabrics produced on traditional handlooms are used for ceremonial dress, chieftaincy regalia, rites of passage, and contemporary fashion expressions. These textiles are valued not only for their symbolic meanings but also for the craftsmanship embedded in their structures and patterns (Clifford Collard, 2017). However, despite their cultural importance, the technical capabilities of indigenous handlooms remain largely constrained by simple shedding systems, typically based on two heddles or manually manipulated auxiliary sheds. The simplicity of these shedding mechanisms limits the range of weave structures that can be produced efficiently. Plain weave, rib variations, and manually picked tapestry effects dominate indigenous handloom production, while more complex structures such as multi-shaft twills, satins, and compound patterns require time-consuming hand picking or are not feasible at all (Decrette & Drean, 2022; Gokarneshan & Ratna, 2021). As a result, indigenous weavers face increasing challenges in responding to contemporary market demands that favour greater structural complexity, improved drape, and refined surface aesthetics.

Existing scholarly work on handloom weaving largely follows two parallel directions. One body of literature focuses on cultural preservation, documentation of motifs, and safeguarding traditional weaving knowledge (Ingold, 2000). Another body of work examines mechanised or semi-mechanised weaving technologies within industrial or factory-based contexts, emphasising productivity, automation, and standardisation (Decrette & Drean, 2022). While both approaches contribute valuable insights, they leave limited space for exploring intermediate technological adaptations that enhance indigenous looms without transforming them into industrial systems. Recent studies have begun to argue that selective technological integration may offer a viable pathway for sustaining indigenous weaving practices while improving efficiency and design capability (Mamidipudi, & Gajjala, 2008). Among such technologies, the countershaft shedding mechanism is notable for its ability to control multiple harnesses through coordinated treadle, lams and lever systems. Unlike fully mechanised solutions, the countershaft mechanism can be integrated into traditional handlooms while preserving the embodied skills and manual rhythm of hand weaving. Despite this potential, empirical research on the application of countershaft shedding mechanisms within indigenous handloom contexts remains limited. Existing studies often

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describe loom modifications without systematically analysing how enhanced shedding control influences woven fabric structure, pattern precision, or observable fabric quality. Furthermore, the perspectives of indigenous weavers, particularly regarding usability, ergonomics, and creative freedom, are seldom integrated into technical analyses of loom performance.

This study responds to these gaps by examining woven fabric structures produced on an indigenous handloom integrated with a countershaft shedding mechanism. By analysing fabric samples woven across multiple shaft configurations, the study investigates how expanded shedding capacity affects weave complexity, pattern formation, and structural consistency. In addition, qualitative insights from experienced weavers provide contextual understanding of the practical implications of adopting the countershaft system within traditional weaving environments. The originality of this study lies in its combined focus on fabric structure analysis and practitioner experience within an indigenous handloom framework. Rather than treating technological enhancement and cultural preservation as opposing goals, the study demonstrates how controlled mechanical adaptation can expand creative and technical possibilities while retaining the cultural logic of hand weaving. The study contributes to textile scholarship by providing empirical evidence on the structural implications of countershaft shedding mechanisms in indigenous looms, offering a practical framework for loom upgrading that avoids full mechanisation, and informing sustainable textile development by aligning technological innovation with cultural continuity. By doing so, it supports broader efforts to position indigenous handwoven textiles as relevant, competitive, and culturally grounded within contemporary textile markets. The remainder of this paper is organised as follows. The next section reviews relevant literature on indigenous handloom weaving, shedding mechanisms, and fabric structural behaviour. This is followed by a description of the materials and methods employed in the study. The results and discussion sections present and interpret the structural characteristics of the woven fabrics. The paper concludes with implications of the findings, limitations of the study, and directions for future research.

2 | REVIEW OF RELATED LITERATURE

2.1| Indigenous Handloom Weaving and Cultural Significance

Indigenous handloom weaving has long been recognised as both a cultural and technological practice, deeply embedded in social life and artistic expression. Handwoven textiles often function as carriers of symbolic meaning, reflecting community identity, hierarchy, and belief systems. In many African and Asian contexts, weaving knowledge is transmitted orally and practically, forming part of intangible cultural heritage rather than formalised technical systems (Ingold, 2000; Mamidipudi & Bijker, 2018). In Ghana, indigenous narrow strip weaving remains a dominant form of handloom practice. These textiles are integral to ceremonial attire, chieftaincy regalia, and contemporary fashion, while also contributing to household economies within weaving communities (Clifford Collard, 2017). The visual richness of these fabrics is achieved largely through colour arrangement, strip assembly, and symbolic patterning rather than through complex weave structures. As a result, the technical evolution of indigenous looms has historically prioritised cultural continuity over structural innovation. While scholars emphasise the need to preserve traditional weaving practices, several studies acknowledge that rigid adherence to static technologies can limit the economic sustainability of handloom industries in contemporary markets. This tension between preservation and adaptation provides the broader context within which technological enhancement of indigenous looms must be evaluated.

2.2| Shedding Mechanisms in Handloom Weaving

Shedding is a fundamental operation in weaving, determining how warp yarns are separated to allow weft insertion. The nature of the shedding mechanism directly influences the range of weave structures that can be produced, as well as fabric regularity and efficiency of production (Decrette & Drean, 2022). Traditional handlooms typically employ simple shedding systems, including stick shedding, two heddle arrangements, or manually manipulated auxiliary sheds. Such systems are adequate for producing plain weaves and simple derivatives, but become increasingly inefficient as pattern complexity increases. Producing advanced weave structures often requires hand-picking of individual warp yarns, which is labour-intensive and prone to inconsistency (Gokarneshan & Ratna, 2021). Consequently, the technical limitations of shedding mechanisms play a critical role in shaping the aesthetic and structural characteristics of indigenous handwoven textiles. Advancements in shedding technology within industrial weaving, including dobby and jacquard systems, demonstrate how increased control over warp yarns

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enables complex structures, higher precision, and improved fabric consistency (Adanur, 2000; Decrette & Drean, 2022). However, these systems are generally incompatible with indigenous handloom contexts due to their cost, energy requirements, and departure from manual weaving practices.

2.3| Countershaft Shedding Mechanism and Loom Adaptation

The countershaft shedding mechanism occupies an intermediate position between basic handloom shedding and fully mechanised systems. It operates through coordinated interaction between treadles, lams, levers, and an oscillating shaft, allowing multiple harnesses to be lifted in a controlled sequence. This configuration enables the production of multi-shaft weave structures while retaining manual operation (Gokarneshan & Ratna, 2021). Studies on handloom modernisation suggest that countershaft systems can significantly expand design capability without fundamentally altering the artisanal nature of weaving (Mamidipudi, & Gajjala, 2008). By distributing mechanical effort through treadling rather than manual heddle lifting, the countershaft mechanism improves operational efficiency and reduces physical strain on the weaver (Hanumegowda et al., 2021). Nevertheless, much of the existing literature focuses on loom construction or conceptual discussions of technological integration. There is limited empirical evidence examining how countershaft integration influences fabric structure when applied to indigenous handlooms. Furthermore, discussions often emphasise productivity gains without adequately addressing changes in weave formation, pattern accuracy, or structural consistency of the resulting fabrics.

2.4| Fabric Structure and Weave Complexity

Fabric structure is defined by the interlacement of warp and weft yarns, which determines mechanical behaviour, surface texture, and aesthetic qualities such as drape and pattern clarity. Weave structures such as twills, satins, and compound weaves are known to offer greater flexibility, improved drape, and enhanced visual richness compared to plain weave structures (Adanur, 2000; Decrette & Drean, 2022). Research indicates that the ability to control multiple shafts with consistent warp tension is essential for producing structurally stable complex weaves (Vigbedor et al., 2024; Mahato & Das, 2019). Multi-shaft twills, for example, distribute stress more evenly across the fabric, while satin structures produce smoother surfaces through controlled float distribution. However, achieving these structures on indigenous looms remains challenging due to shedding limitations. The relationship between shedding precision and pattern accuracy has also been highlighted in weaving studies. Inconsistent shed formation can lead to irregular interlacements, pattern distortion, and uneven fabric surfaces (Kumar & Hu, 2018). As such, enhanced shedding control is directly linked to improved structural reliability and repeatability in woven fabrics.

2.5| Weaver Experience, Ergonomics, and Usability

Beyond fabric outcomes, loom technology significantly affects the physical and cognitive experience of the weaver. Traditional handlooms often require repetitive upper body movements, including manual lifting of heddles and auxiliary sheds, which can result in fatigue and long-term musculoskeletal strain. Studies on loom ergonomics suggest that redistributing effort to treadle-based systems reduces physical strain and allows weavers to sustain longer working periods with greater comfort (Hanumegowda et al., 2021). Improved ergonomics also influence creative engagement, as weavers are able to focus more on pattern development rather than mechanical manipulation. However, empirical accounts of weaver perceptions remain underrepresented in technical textile research. Integrating practitioner insights into loom performance studies is essential for evaluating the cultural acceptability and adoption potential of technological innovations within indigenous weaving communities.

2.6| Research Gap

From the reviewed literature, it is evident that while the cultural importance of indigenous handloom weaving is well documented, and the technical advantages of advanced shedding mechanisms are established in industrial contexts, there is limited research bridging these domains. Specifically, there is a lack of systematic analysis of woven fabric structures produced on indigenous handlooms integrated with countershaft shedding mechanisms. Existing studies rarely combine structural fabric analysis with qualitative evaluation of weaver experience. As a result, the implications of countershaft integration for

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weave complexity, pattern accuracy, and practical usability within indigenous contexts remain insufficiently explored. This gap forms the basis for the present study.

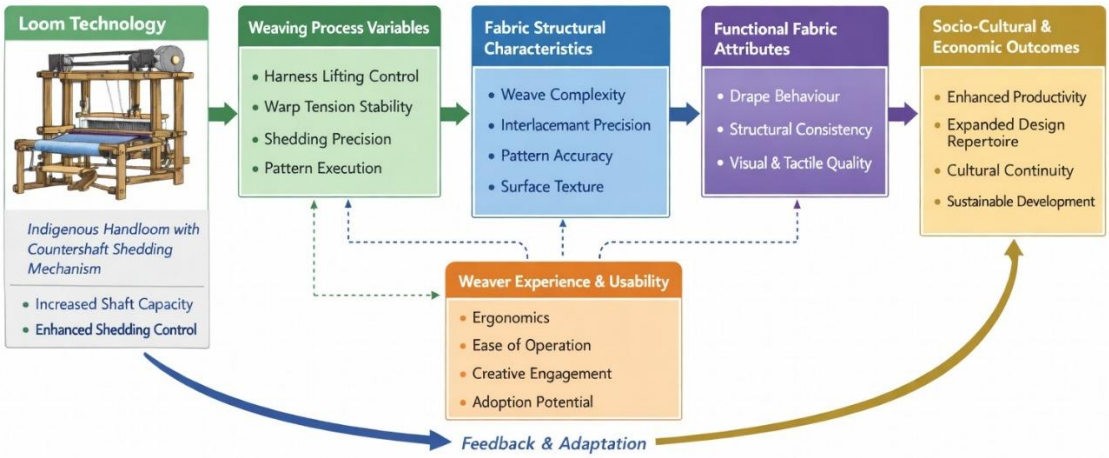


Figure 1. Conceptual framework on the indigenous handloom weaving experience

3 | MATERIALS AND METHODS

3.1| Loom Configuration

An indigenous horizontal handloom was modified to incorporate a countershaft shedding mechanism. The system connected treadles to harnesses through lams, levers, pulleys, and a rotating countershaft, enabling controlled lifting of multiple shafts. Countershaft mechanisms are recognised for improving shedding precision and enabling multi-shaft weaving while maintaining manual loom operation (Gokarneshan, 2026; Hanumegowda et al., 2021). The loom remained fully manually operated, with no automated components. The configuration allowed weaving with four to eight shafts, improving shed clarity and warp separation compared to conventional two-heddle indigenous looms, as documented in handloom adaptation studies (Adanur, 2000).

3.2| Materials

Warp Yarns

The warp yarn consisted of ring-spun cotton, specification Ne 20/2 with a Z-twist. Yarns of this count and construction are favoured in handloom weaving for their optimal balance of strength and flexibility (Kadolph & Marcketti, 2010). Prior to weaving, the warp was manually sized with starch, a standard preparatory practice in handloom weaving, to enhance abrasion resistance and reduce yarn breakage during shedding (Decrette & Drean, 2022).

Weft Yarns

A 150-denier, single-ply viscose rayon filament yarn was employed as the weft. Rayon is commonly chosen in handweaving for its smooth surface, inherent lustre, and superior drape, which collectively improve the visual definition and clarity of woven structures (Kadolph & Marcketti, 2010).

3.3| Methods

3.3.1| Weave Structures and Fabric Production

Fabric samples were woven using two to eight shaft configurations, producing plain weave derivatives, twills, diamond weaves, and satin-based structures. Multi-shaft weaving trials are recognised as an effective method for examining the relationship between shedding mechanisms and weave complexity (Gokarneshan, 2026). Weave drafts, heddling orders, and treadling plans were developed using WeavePoint software, which has been widely adopted for accurate weave drafting and pattern planning in textile research and practice (Adanur, 2000). Warp tension, pick density, and beat-up were kept consistent across all samples to minimise variability unrelated to loom performance.

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3.3.2| Data Collection and Analysis

Data collection combined structural, mechanical, and qualitative approaches to evaluate the countershaft shedding mechanism comprehensively.

Structural Analysis: Fabric samples were examined for weave structure and design consistency. Optical microscopy provided detailed observations of interlacement and surface texture.

Mechanical and Functional Assessment: Tensile strength was measured using a Mark 10 ESM301L tensile tester from the University of Ghana, in accordance with ASTM D3822 standard tests, to evaluate the fabric's strength. While manual handling by experienced artisans assessed flexibility, flow, and drape.

Weaver Survey: Semi-structured interviews were conducted with 20 experienced artisans (10 from Bonwire, 10 from Agotime-Kpetoe) to capture perceptions of ease of use, productivity, physical effort, and adoption potential of the countershaft system (Mamidipudi & Gajjala, 2008). Quantitative data were analysed descriptively, and qualitative responses were thematically interpreted. Together, these methods provided a holistic assessment of fabric structure, functional performance, and user acceptability.

3.4| Ethical Considerations

Weaver participation was voluntary, and no personal identifiers were collected. The study complied with standard ethical research practices for studies involving human participants.

4 | RESULTS AND DISCUSSION

4.1| Loom Performance and Weaving Speed

The integration of the countershaft shedding mechanism significantly improved the operational efficiency of the indigenous handloom. The modified loom achieved 25 picks per minute, compared to 15 picks per minute on conventional two-heddle looms, demonstrating a clear enhancement in weaving speed. This improvement is attributed to the mechanical advantage of levers and lams, which reduce physical exertion, and the synchronised shed formation through a rotating shaft, allowing consistent and rapid shedding (Decrette & Drean, 2022; Mamidipudi & Gajjala, 2008).

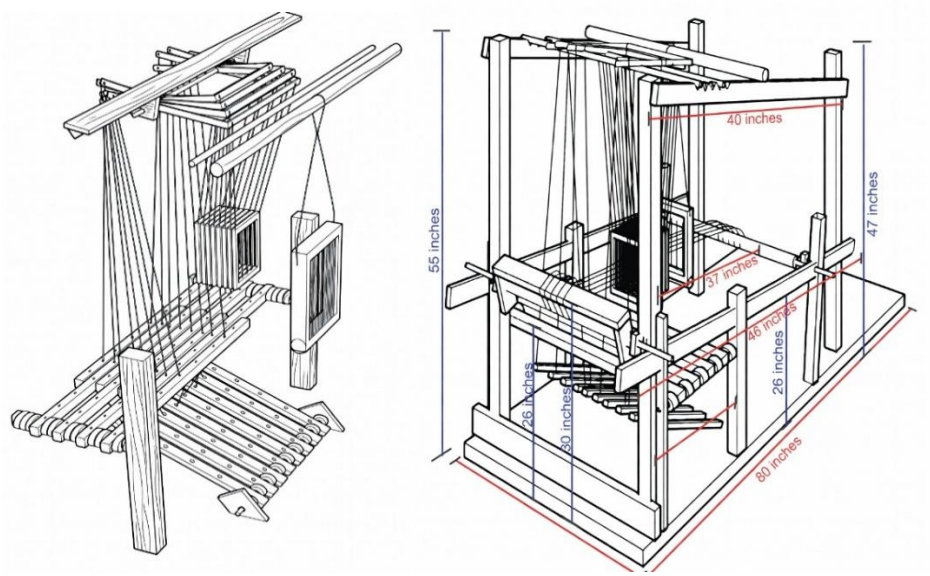


Figure 2. Assemblage of Countershaft shedding Mechanism (Vigbedor et al., 2024)

The countershaft system streamlined workflow by reducing idle time associated with manual heald lifting, enabling weavers to focus on essential operations such as weft insertion and beat-up. These improvements were confirmed by survey responses, where artisans noted reduced physical strain and faster weaving cycles (Vigbedor et al., 2024; Mahato & Das, 2019). The results align with prior studies demonstrating that intermediate mechanisation in handlooms can enhance productivity without compromising artisanal quality (Hanumegowda et al., 2021; Bortamuly & Goswami, 2015).

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Figure 3. (a) *Ahwepan*, (b) *Nwa toa,* (c) *Baba Dua,* and (d) *Ahwe pan*

4.1.1| Pattern Generation and Analysis of Countershaft Handwoven Mechanism

WeavePoint software was employed to design and visualise woven structures by specifying heddling and treadling sequences (Puarungroj & Boonsirisumpun, 2019). These digital Fabric Structure Samples (FSS) were then woven on a countershaft handloom configured with 4–6 shafts. Select treadles generated the pattern, while others acted as binders for stability. Weft yarns were inserted in a controlled colour sequence to enhance texture and depth. Each resulting Woven Fabric Sample (WFS) is documented by its shaft count, draft, tie-up, treading order, and colour insertion. Each sample is described in terms of:

i. Number of shafts and treadles
ii. Warp threading (heddling) order
iii. Treadle tie-up configuration
iv. Treadling (lifting) sequence
v. Weft colour insertion pattern.

Four-Shaft System

Warp Rib (sample 1), using a 4-shaft configuration with a repeated heddling order of (1, 2, 1, 4, 3, 4) and a treadling order of 1, 2 (with treadles 3 and 4 as binders), a warp-rib structure was achieved (Figures 4(a)) to produce a weft face and simple plain weaves, shown in Figure 4(b) and 4(c). The result is a plain weave derivative with a ribbed texture, demonstrating how basic heddling and treadling variations can yield structurally distinct fabrics. Twill Weave (sample 4), a four-shaft twill was produced using a heddling order of (1, 2, 1, 4, 3, 4) and a tie-up connecting treadles T1–T4 to shaft pairs (1&2, 2&3, 3&4, 4&1). Treadles T5 and T6 were used as plain-weave binders. The heddling sequence (1, 2, 3, 4, 3, 2) produced a diagonal twill pattern, as shown in Figure 4(d).

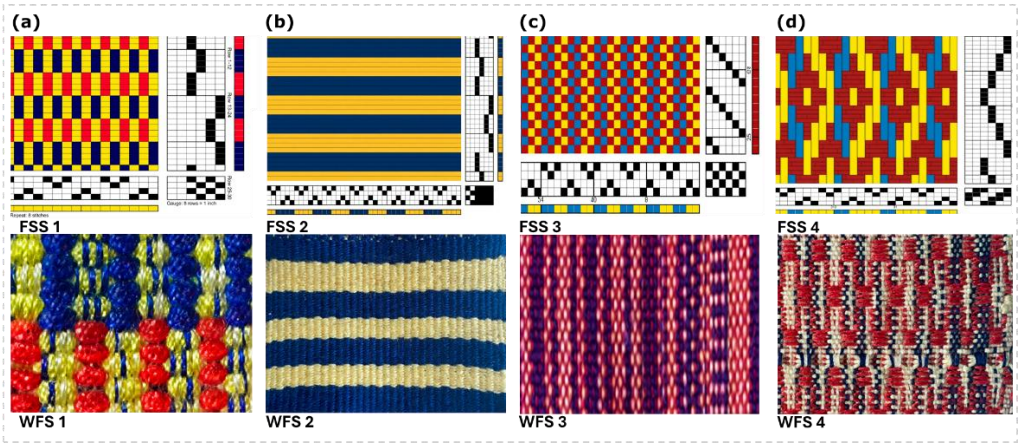


Figure 4. (a) Warp Rib (sample 1), (b) Weft Face Weave (sample 2), (c) Simple Plain Weave (sample 3) and (d) Twill Weave (sample 4)

Five-Shaft System

Five harnesses enabled more complex designs, including zig-zag twill, vertical wavy twill, symmetrical grid twill, and multiple diamond weaves. All samples employed seven treadles with strategic tie-ups to shaft pairs or triples. The use of two or three weft colours, inserted in alternating sequences, added depth and contrast.

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Zig-Zag Twill Weave (sample 1), a straight draft of (1, 2, 3, 4, 5) and a point-reverse lifting plan (1, 2, 3, 4, 5, 4, 3, 2) created a zig-zag twill (Figure 5(a)). Yellow weft followed T1–T5 in sequence (1-2-3-4, 5-4-3-2), while green weft alternated on T6 and T7. The alternating colour insertion creates depth and visual interest in the final woven fabric. The Vertical Wavy Twill Weave (sample 2), as shown in Figure 5(b), was produced using five shafts and seven treadles. A straight draft threading (1-2-3-4-5, repeated) and a stepped lifting sequence (1-2-3-4-5; 4-3-2) were employed. Treadles were tied to shafts in the following pairs: T1(1&2), T2(2&3), T3(3&4), T4(4&5), T5(5&1), T6(1&3), and T7(2&4). Three weft colours, yellow, orange, and blue, were introduced in a controlled sequence: yellow using T1–T5, orange using T4–T2 in reverse, and blue alternated with T6 and T7. This interplay of threading, tie-up, and colour insertion creates a vertical wavy effect, resulting in a fabric with rich colour interaction and textural complexity.

Symmetrical Grid Twill (sample 3), presented in Figure 5(c), was produced on a five-harness loom using seven treadles. A straight draft threading (1-2-3-4-5, repeated) was combined with a structured lifting sequence (1-2-3-4-5, 1-2, 3-4-5, 4-3-2-1, 5-4-3-2). Treadles were tied to shafts in paired combinations; T1(1&2), T2(2&3), T3(3&4), T4(4&5), T5(5&1), T6(1&3), and T7(2&4). Purple weft was introduced using treadles T1 through T5, while blue weft was alternately inserted via T6 and T7. This strategic alternation of blue weft creates contrast, enhancing both the complexity and visual appeal of the resulting symmetrical grid twill. Diamond Weave (sample 4), as shown in Figure 5(d) presents a diamond weave derived from a 2/3 twill structure, produced on five shafts. The pattern was achieved using a point draft threading sequence (1-2-1, 2-3-2, 3-4-3, 4-5-4, 5-1-5, 4-5-4, 3-4-3, 2-3-2) and a stepping order of (1-2-3-4-5, 4-3-2). Purple weft was inserted through treadles T1–T5, while blue weft was alternated using T6 and T7, T1(1&2), T2(2&3), T3(3&4), T4(4&5), T5(5&1), T6(1,3&5), T7(2&4). This method produces a raised diamond motif set against a firm plain-weave background, enhancing both texture and visual depth.

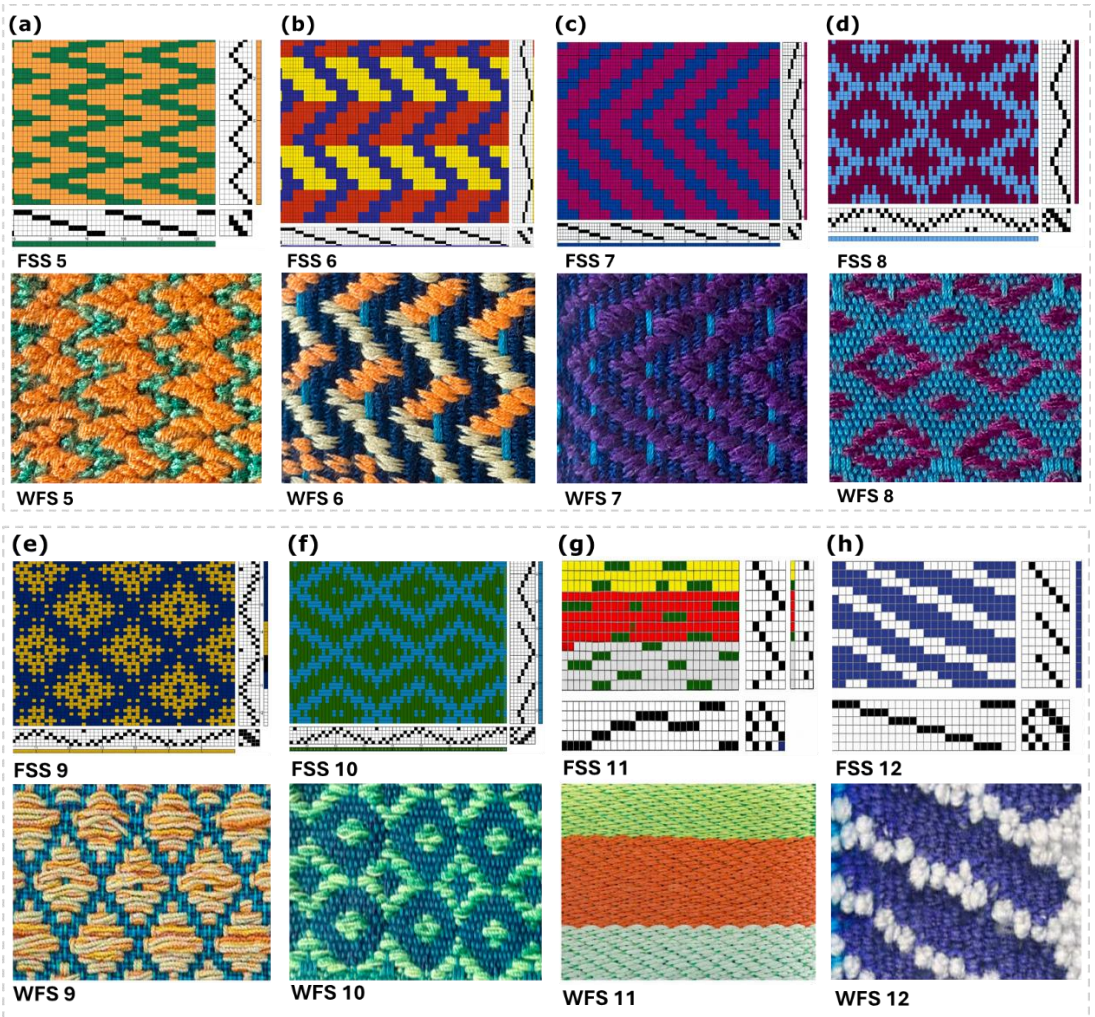


Figure 5. (a) Zig-Zag Twill Weave (b) Vertical Wavy Twill Weave (sample 2), (c) Symmetrical Grid Twill (sample 3), (d) Diamond Weave (sample 4), (e) Diamond Weave (sample 5), (f) Wavy Diamond Weave (sample 6), (g) Sateen Weave (sample 7), (h) Step-wise Twill Weave (sample 8)

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Diamond Weave (sample 5), as shown in Figure 5(e), depicts a diamond weave based on a 3/2 twill structure, woven on five shafts. A point draft threading sequence and mirrored stepping order were used, with treadles T1–T7 tied to specific shaft combinations. Yellow weft was inserted via T1–T5, followed by alternating blue weft on T6 and T7. The warp threading follows a point draft sequence (1-2-, 2-3-2, 3-4-3, 4-5-4, 5-1-5, 4-5-4, 3-4-3, 2-3-2). Seven treadles (T1-T7) tie-up to shaftsfollow the order: T1(1-4-5), T2(3-4-5), T3(2-3-4), T4(1-2-3), T5(1-2-5), T6(2-4), T7(1-3-5).This produces a textured diamond relief against a firm plain background, resulting in a visually complex and contrasting fabric design. The Wavy Diamond Weave (sample 6), as shown in Figure 5(f), is a 2/2 twill variant produced on five shafts. A point draft threading (e.g., 1-2-1, 2-3-2, 3-4-3, 4-5-4, 5-1-5, 4-5-4, 3-4-3, 2-3-2) and a mirrored stepping order, (1-2-3-4-5, 4-3-2-1; 5-4-3-2-1, 2-3-4-5) create the foundational diamond grid. Seven treadles (T1–T7) are tied to specific shaft triples and pairs, controlling the raised ends. Green weft is inserted using T1–T5, T1(1,4,5), T2(3,4,5), T3(2,3,4), T4(1,2,3), T5(1,2,5), T6(2,4), T7(1,3,5), while blue weft alternates on T6 and T7. This selective weft placement generates a firm primary diamond pattern adorned with smaller, floating relief diamonds, resulting in a textured, layered visual effect.

Sateen Weave (Sample 7), using a straight draft (1-2-3-4-5) and stepping order (1-3-5-2-4), resulted in a sateen structure with scattered green spots (Figure 5(g). White, orange, yellow, and green wefts were inserted in a specific sequence, with green introduced via T6 and T7 to create the spotted effect. The Step-wise Twill Weave (sample 8), as shown in Figure 5(h), is a five-shaft structure using a straight draft (1-2-3-4-5 repeated) and a non-sequential stepping order (1-3-5-2-4). Seven treadles are tied to shaft pairs: T1(1&2) to T5(5&1), with T6(1&3) and T7(2&4). Blue weft is inserted via T1–T5 in the stepping order. After each blue pick, white weft is alternated using T6 and T7. This staggered treadling sequence produces a fabric with distinct, diagonal step-wise lines.

Six-Shaft System

The Zig-Zag Diamond Weave (sample 1) as shown in Figure 6(a) was created on six shafts using a detailed point-draft threading (1-2-1, 2-3-2, 3-4-3, 4-5-4, 5-6-5, 6-1-6, 5-6-5, 4-5-4, 3-4-3, 2-3-2, 1-2-1, 6-1-6, 5-6-5, 4-5-4, 3-4-3, 2-3-2, 1-2-1, 6-1-6) and a stepping order of (1-2-3-4-5-6; 5-4-3-2). Eight treadles were tied to specific shaft pairs and triples. Brown weft was inserted via T1–T6, while blue weft alternated on T7 and T8. This technique produces a raised, zig-zagging diamond motif with pronounced floats, set against a solid plain-weave background. The Interlocking Diamond Weave (sample 2) as shown in Figure 6(b) was produced on six shafts using a detailed point-draft threading sequence and a multi-phase stepping order (1-2-1, 2-3-2, 3-4-3, 4-5-4, 5-6-5, 6-1-6, 5-6-5, 4-5-4, 3-4-3, 2-3-2, 1-2-1, 6-1-6, 5-6-5, 4-5-4, 3-4-3, 2-3-2, 1-2-1, 6-1-6). Eight treadles were tied to shaft pairs and triples (e.g., 1&2, 2&3, 3&4, 4&5, 5&6, 6&1, 1,3 & 5, and 2, 4 & 6).

Brown weft was inserted following the stepping order via T1–T6, (123456; 5432; 654321; 23456; 54321; 23456) while blue weft alternated on T7 and T8 after each brown pick. This precise colour alternation against the complex draft creates layered, interlocking diamond motifs with pronounced textural contrast. The Overlapping Diamond Weave (sample 3) as shown in Figure 6(c) was woven on six shafts using a point-draft threading sequence (1-2-1, 2-3-2, 3-4-3, 4-5-4, 5-6-5, 6-1-6, 5-6-5, 4-5-4, 3-4-3, 2-3-2, 1-2-1, 6-1-6, 5-6-5, 4-5-4, 3-4-3, 2-3-2, 1-2-1, and 6-1-6) and a stepping order of (1-2-3-4-5-6, 5-4-3-2). Eight treadles were tied to shaft pairs and triples (e.g., T1-1&2, T2-2&3, T3-3&4, T4-4&5, T5-5&6, T6-6&1, T7-1,3&5, and T8-2,4&6). White weft was inserted via T1–T6, while blue weft alternated on T7 and T8 after each pick. This precise colour sequencing creates layered, overlapping diamond motifs against a solid plain-weave background.

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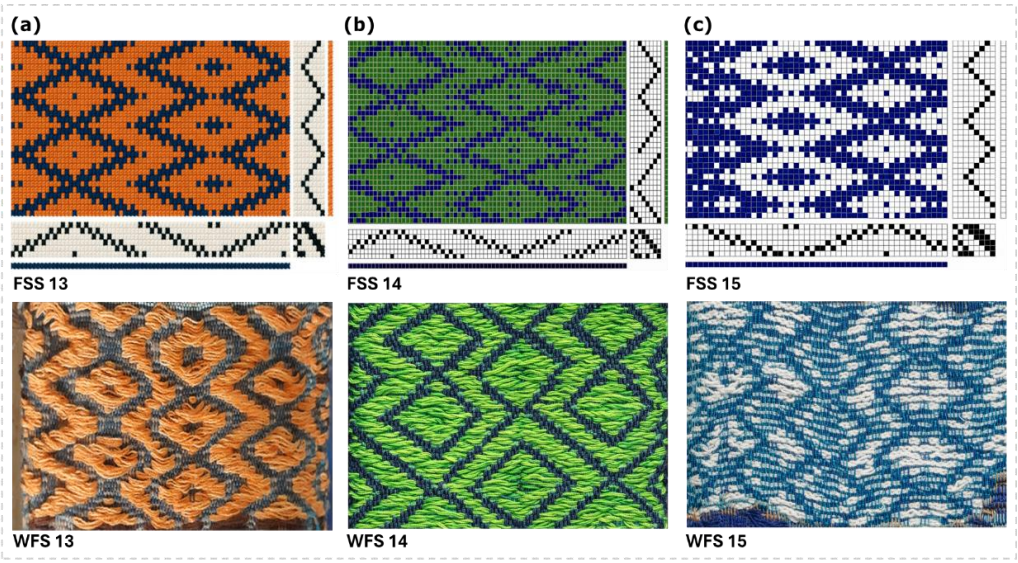


Figure 6. Six-Shaft System (a) Zig-Zag Diamond Weave (sample 1), (b) Interlocking Diamond Weave (sample 2), (c) Overlapping Diamond Weave (sample 3)

4.1.2| Functional Properties and Drapability

Mechanical and tactile assessments showed that fabrics woven on the countershaft loom exhibited improved flexibility and drape. Stiffness testing and manual handling confirmed that multi-shaft fabrics flow more smoothly and exhibit higher structural uniformity compared to conventional fabrics, which remain relatively stiff due to limited interlacement options (Lord et al., 1982; Kadolph & Marcketti, 2010). These functional improvements make the fabrics suitable for both traditional ceremonial use and modern textile applications.

4.2| Integrated Tensile and Fabric Quality Analysis

The tensile strength results for all samples (ON1–ON3 and S1–S3), tested in both vertical (warp-dominated) and horizontal (weft-dominated) directions, collectively demonstrate that loom mechanism and weave geometry decisively influence fabric mechanical behaviour. Across the ON series, fabrics woven on the countershaft lever system consistently showed improved structural efficiency, most importantly with a basic shaft lever mechanism of four and a maximum of six for the S series, particularly in the vertical direction, compared with their conventional handloom counterparts. This improvement is evident in steeper stress–strain responses and higher load-bearing capacity at equivalent strain levels, indicating superior warp engagement and a more uniform stress distribution. Similar behaviour is observed in shedding mechanisms that reduce stress concentrations and enhance tensile efficiency in woven structures (Decrette & Drean, 2022).

For ON1, based on the four-shaft lever mechanism (Figure 4(a), WFS 1), a visual comparison in Figure 7(a) and 7(b) shows improved surface regularity and yarn alignment in the countershaft-woven fabric relative to the conventional sample. This structural improvement is reflected in the tensile response shown in Figure 7(c). In the vertical direction, the countershaft fabric exhibits a steeper initial stress–strain slope and a higher peak stress before failure, indicating improved load transfer along the warp yarns and reduced stress concentration. The conventional fabric, by contrast, shows earlier yielding and lower ultimate stress, suggesting uneven warp tension during weaving. In the horizontal direction, both fabrics exhibit lower tensile strength; however, the countershaft fabric maintains a more stable stress–strain curve with delayed rupture. Similar behaviour has been reported in controlled shedding systems, where consistent shed geometry enhances warp engagement and tensile efficiency (Decrette & Drean, 2022; Adanur, 2000).

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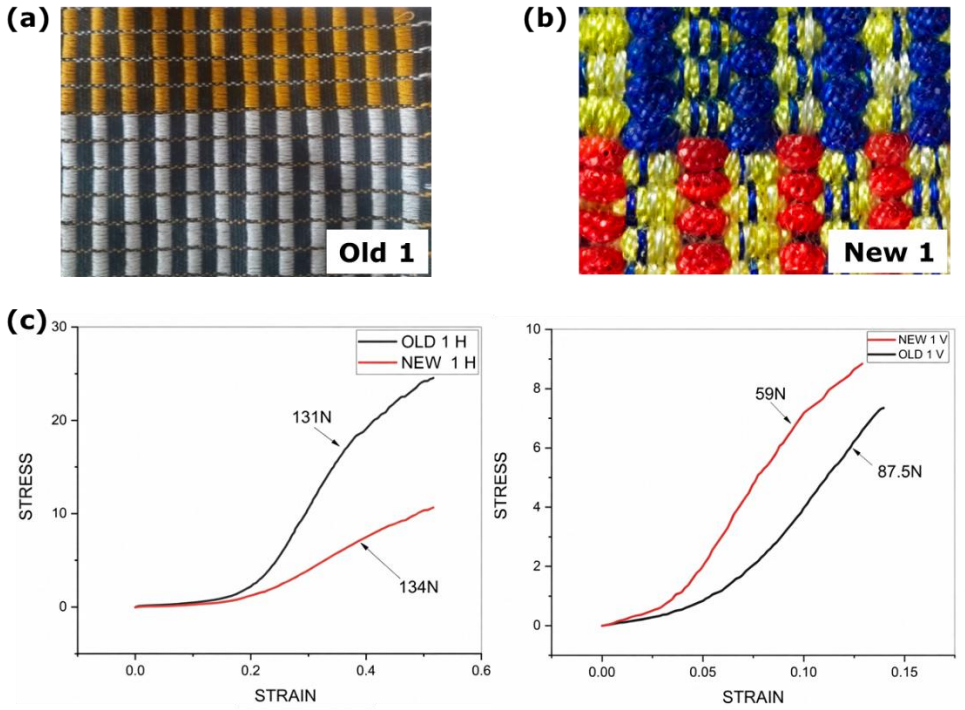


Figure 7. (a) conventional woven fabric, (b) countershaft loom woven fabric and (c) Tensile strength test, vertical and horizontal direction test (ON1)

A trend is observed for ON2, as shown in Figure 4(b) (WFS 2), which reveals a clearer interlacement definition and reduced waviness in the countershaft fabric. Correspondingly, Figure 8(c) shows that the countershaft-woven sample achieves higher stress values at comparable strain levels in both directions. The vertical tensile curve again demonstrates superior stiffness and higher failure stress, while the horizontal response shows improved strain tolerance before rupture. This indicates more uniform stress distribution between warp and weft yarns, which is consistent with established fabric mechanics theory linking controlled warp tension to enhanced tensile behaviour (Gokarneshan & Ratna, 2021).

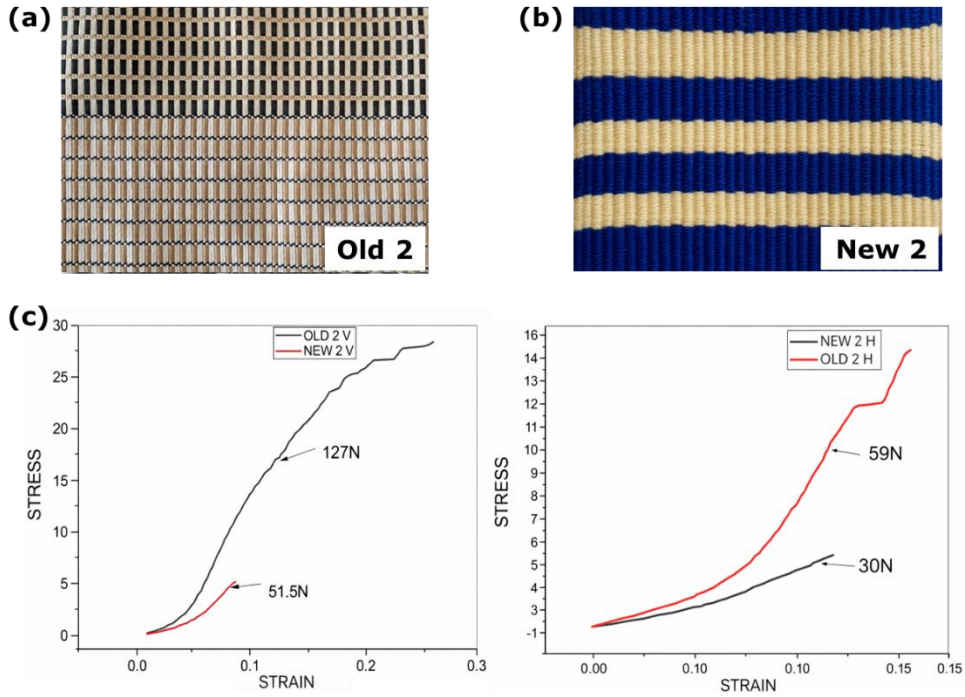


Figure 8. (a) conventional woven fabric, (b) countershaft loom woven fabric and (c) Tensile strength test, vertical and horizontal direction test (ON2)

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The results for ON3 further reinforce this pattern. As seen in Figure 9(a) and 9(b), the countershaft fabric exhibits improved structural clarity compared to the conventional sample. In Figure 9(c), the stress–strain curves show that the countershaft fabric sustains higher applied stress with reduced scatter in the deformation region, indicating improved structural stability. The conventional fabric displays greater variability and earlier failure, particularly in the vertical direction. These findings confirm that the countershaft mechanism reduces yarn slippage and promotes more efficient stress sharing across the fabric structure, as also observed in multi-shaft loom studies by Lord and Mohamed (1982).

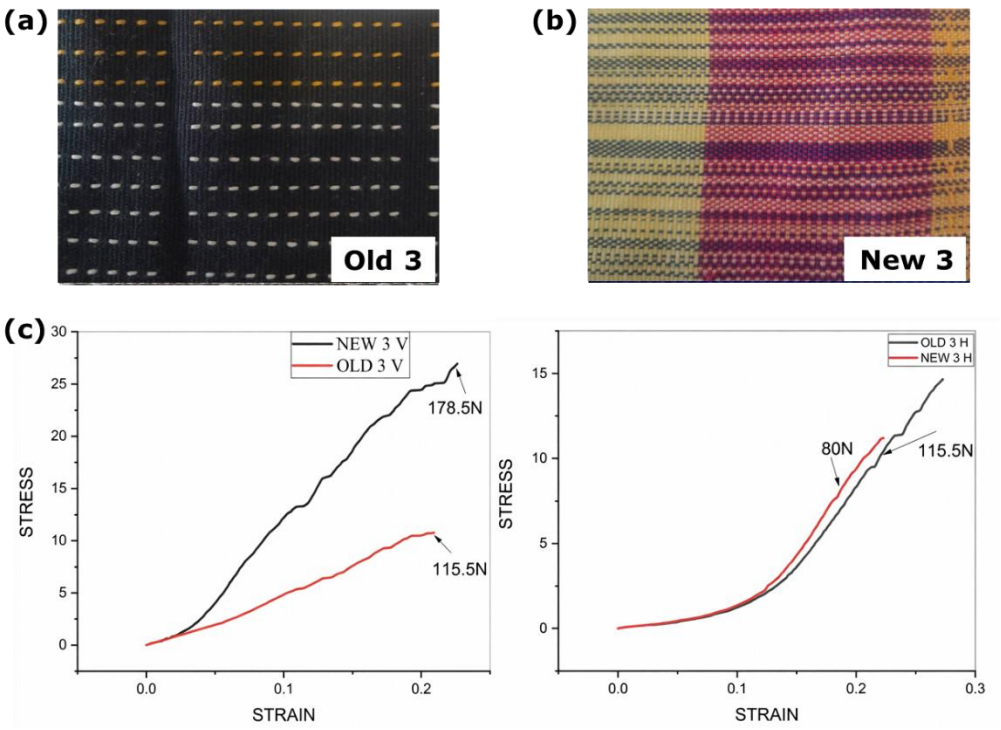


Figure 9. (a) conventional woven fabric, (b) countershaft loom woven fabric and (c) Tensile strength test, vertical and horizontal direction test (ON3)

The influence of weave geometry is further illustrated in the countershaft-only samples S1 to S3. Figure 10(a)-10(c) shows the structural differences among straight twill (S1 -4 shaft mechanism), pointed twill (S2- five shaft weaving mechanism; WFS 5), and diamond twill (S3-6-8 shaft mechanism; WFS 13), while Figure 10(d) presents their tensile responses. The straight twill (S1) exhibits the highest tensile strength in the vertical direction, characterised by a steep stress–strain slope and high peak stress, reflecting its relatively short floats and efficient load-bearing path. The pointed twill (S2) shows increased strain at failure, indicating enhanced flexibility and balanced deformation behaviour. Obasi et al. (2024) observed that symmetrical twill reversals enhance lateral strength while compromising axial load efficiency. The diamond twill (S3) demonstrated a more uniform tensile response in both directions, with moderate peak stress and improved strain distribution, suggesting balanced stress transfer across the fabric axes. These results align with classical textile structure–property relationships, where float length and interlacement frequency directly influence tensile strength and extensibility (Adanur, 2000).

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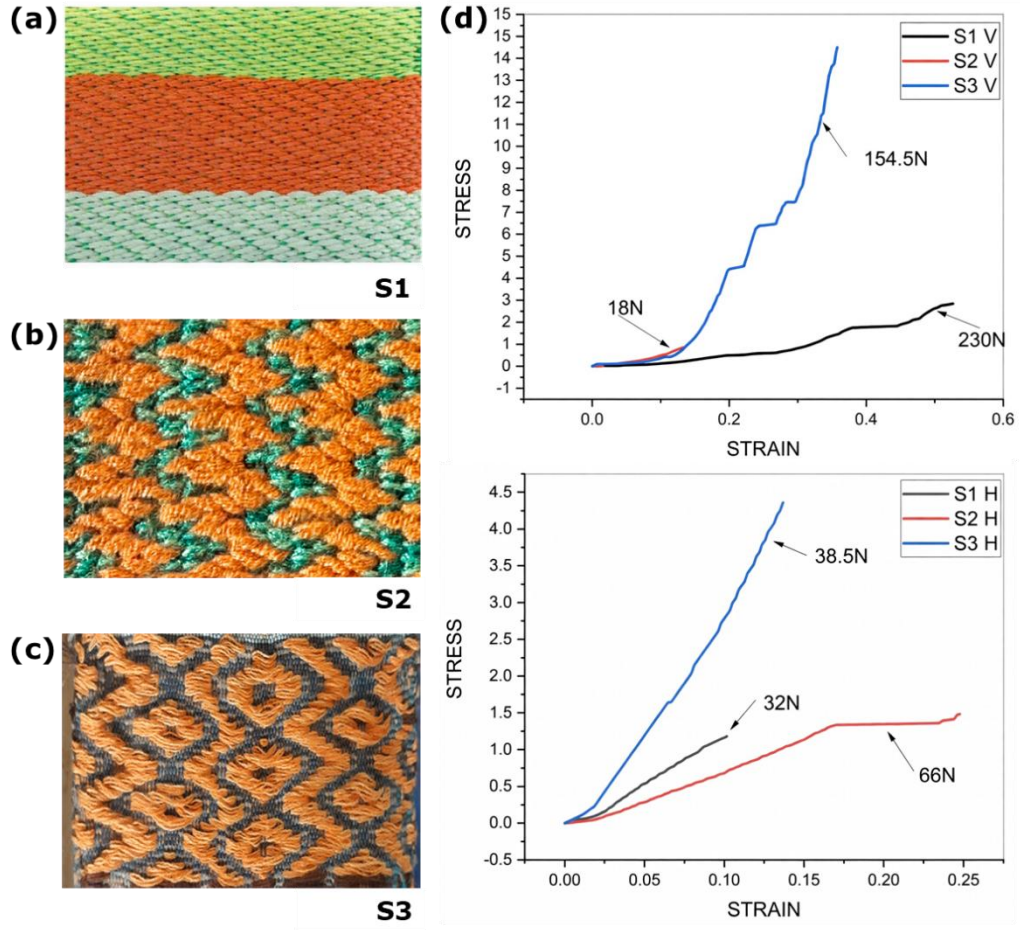


Figure 10. Countershaft loom woven fabrics (a) Straight twill (b) Pointed Twill (c) Diamond twill, and (d) Tensile strength test, vertical and horizontal direction test (S1, S2 and S3)

In all, an assessment of the ON and S-series results confirms that the countershaft lever system fundamentally enhances warp-direction performance by improving tension regulation, reducing yarn mobility, and enabling precise interlacement. While conventional fabrics may still achieve higher peak loads in the weft direction, their performance is less efficient at operational strain levels. This trade-off between extensibility and stiffness mirrors conclusions by Hanumegowda et al. (2021), who argue that modernised handloom mechanisms optimise functional performance without eliminating the aesthetic and cultural qualities of traditional textiles.

Table 1. Tensile Performance and Mechanical Character

Fabric / Weave Type	Vertical Tensile Strength (N)	Horizontal Tensile Strength (N)	Mechanical Character	Key Properties	Typical / Potential Use
ON1 – Conventional **(O)**	59	115.5	Weft-dominant	High extensibility, lower stiffness	Rugs, mats, decorative textiles
ON1 – Countershaft **(N)**	87.5	80	Warp-efficient	High stiffness, reduced slippage	Apparel, structured fabrics
ON2 – Conventional (O)	127	59	Highly extensible	Delayed resistance	Heavy-duty craft fabrics
ON2 – Countershaft (N)	51.5	30	Stiff but brittle	Early load resistance	Lightweight structured textiles
ON3 – Conventional (O)	115.5	115.5	Balanced but deformable	High peak load	Upholstery, utility fabrics

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ON3 – Countershaft (N)	178.5	80	Warp-dominant	Superior load sharing	Technical and high-strength textiles
S1 – Straight Twill	230	32	Strongly warp-dominant	Long floats, low crimp	Load-bearing, upholstery
S2 – Pointed Twill	18	66	Weft-dominant	Symmetry, flexibility	Fashion, decorative fabrics
S3 – Diamond Twill	154.5	38.5	Balanced	Structural stability	Apparel, interior textiles

4.3| Qualitative Fabric Quality Analysis (Artisan-Centred Perspective)

Qualitative analysis of responses from twenty experienced weavers drawn from the Bonwire and Agortime-Kpetoe weaving communities reveals a strong convergence between laboratory strength measurements and artisan perceptions of fabric quality. Using thematic coding of semi-structured interviews and survey narratives, three dominant themes emerged repeatedly across respondents: improved drape behaviour, enhanced structural integrity and pattern clarity, and greater confidence in fabric performance during use.

Perceived Improvement in Drape and Handle: Respondents steadily reported a clear improvement in the drape and handle of fabrics woven on the countershaft loom, describing them as softer, more fluid, and easier to manipulate during cutting, sewing, and display. This perceived enhancement was often contrasted with traditional two-heddle fabrics, summarised by one Bonwire master weaver's observation:

> *"This cloth bends easily and falls well on the body. It does not stand stiff like the old two-heddle cloth."*

The improved drape of countershaft-woven fabrics was widely acknowledged, with more than two-thirds of participants noting that the material "follows curves better" when draped or worn, a sentiment expressed by one weaver from Agortime-Kpetoe. This observed improvement in drape correlates directly with established textile mechanics, whereby the uniform warp tension and reduced yarn distortion achieved through countershaft weaving enhance fabric harmony (Hearle et al., 1980). Artisans' observations thus align with tensile data indicating more controlled deformation and reduced stiffness variability in countershaft-produced samples.

Structural Integrity and Pattern Accuracy: Respondents further noted enhanced pattern clarity and consistency in motif repetition, describing designs as "cleaner" and "more exact," especially in complex weaves like diamond and pointed twills. One senior weaver stated,

> *"With this loom, the pattern comes out the same from beginning to end. There is less pulling and correction."*

Visual inspection reinforced these observations, revealing fewer distortions, minimal yarn slippage, and more stable interlacements. These findings align with established textile theory, which links stable shedding and balanced yarn tension to improved load distribution and pattern fidelity (Hearle et al., 1980; Lord & Mohamed, 1982).

User Experience and Confidence in Fabric Performance: Artisans reliably associated the firmer, more uniform structure of countershaft-woven fabrics with greater durability and perceived quality, noting that the cloth "feels strong" and inspires confidence in its longevity. As one participant explained:

> *"When you touch it, you feel it is strong. You trust it will last."*

Although this study focuses on fabric structure rather than ergonomics, respondents nonetheless linked ease of weaving to improved consistency and attention to detail. Reduced manual interference during shedding allowed weavers to focus more closely on yarn placement and pattern execution, indirectly enhancing fabric quality. Similar relationships between process stability and textile quality have been documented in both handloom and industrial weaving studies (Maine & Ashby, 2016).

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Perceived Limitations and Trade-Offs: A minority of respondents noted that longer floats in certain weave structures could increase susceptibility to snagging and dirt retention. However, this was generally viewed as an acceptable trade-off, summarised by one artisan's practical assessment:

"Every design has its weakness, but the beauty and strength of this cloth are worth it."

This particular perspective aligns with scholarship on sustainable textile innovation, which acknowledges that thoughtful technical adaptation can enhance functionality while maintaining cultural and aesthetic integrity (Fletcher & Grose, 2012; Gott, 2012).

5 | CONCLUSION AND FUTURE STUDIES

This study demonstrates that integrating a countershaft shedding mechanism into indigenous handloom systems produces measurable improvements in fabric structural performance without undermining traditional weaving practices. Across the analysed samples (ON1–ON3 and S1–S3), countershaft-woven fabrics consistently exhibited enhanced tensile strength, improved warp-direction efficiency, clearer pattern definition, and superior drape behaviour compared to conventionally woven counterparts. These outcomes confirm that controlled shed formation, improved warp tension regulation, and increased shaft capacity collectively strengthen the relationship between weave geometry and fabric properties. The findings, therefore, establish loom mechanics as a critical determinant of fabric quality in handwoven textiles. The study further shows that different twill-based structures respond distinctly to mechanical refinement. Straight twills demonstrated superior load-bearing capacity, pointed twills offered greater flexibility and directional balance, and diamond twills achieved more uniform stress distribution across both fabric axes. This evidence provides a practical framework for aligning weave structure with functional performance requirements, reinforcing the role of structural design decisions in determining end-use suitability of handwoven fabrics. Importantly, the results challenge the assumption that technological intervention diminishes cultural authenticity. Instead, the countershaft mechanism enables more precise execution of traditional motifs and complex pattern repeats within indigenous weaving logic. By enhancing structural control rather than altering aesthetic intent, the system supports cultural continuity while expanding technical capability. This positions countershaft adaptation as a viable strategy for strengthening the material and cultural value of handwoven textiles.

Future research should extend this work through quantitative mechanical testing under standardised laboratory conditions, including tear strength, abrasion resistance, and long-term dimensional stability. Further investigation into yarn type, fibre composition, and sett variations would deepen understanding of structure–property interactions. Comparative life-cycle assessments and market performance studies could also evaluate the broader sustainability and economic impacts of countershaft adoption. Collectively, these directions would advance the integration of traditional craftsmanship with evidence-based textile engineering, reinforcing the relevance of indigenous handwoven fabrics in contemporary and premium textile markets.

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DATA AVAILABILITY STATEMENT

Data sharing applies to this article upon reasonable request from the corresponding author.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest with respect to this paper as declared.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) employed AI to make proper grammatical corrections and generate a conceptual framework in line with the objective of the work.

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