Design Innovation in Broadloom Weaving: Transformation of a 4-Shaft Loom to an 8-Shaft Loom for Complex Woven Structures

Abstract

This study investigates the feasibility of retrofitting a conventional 4-shaft broadloom into an 8-shaft system as a low-cost innovation for enabling complex woven structures in resource-constrained settings. Guided by a practice-based research design and the Double Diamond framework, the project employed WeavePoint software to construct and simulate weave drafts, followed by practical modifications of the loom to test huck-a-back and honeycomb structures. The results indicate that shaft conversion is feasible, producing fabrics that displayed stable interlacements, structurally consistent selvedges, and distinctive patterns under trial conditions. Beyond its technical outcomes, the retrofit represents an example of appropriate technology, reducing reliance on costly imports, prolonging equipment life, and promoting sustainable textile practices. The study further highlights its educational value by expanding opportunities for students and artisans to explore advanced weaves, thereby strengthening problem-solving skills and design innovation. These findings suggest that loom retrofitting can serve as a replicable strategy for weaving education and small-scale textile enterprises, while contributing to broader discussions on sustainability and grassroots innovation in textile design.

Keywords: Broadloom weaving, Loom retrofitting, Appropriate technology, Woven structures, Sustainable textile design.

1. Introduction

The evolution of the weaving loom has been a pivotal force in textile technology, shaping fabric design and innovation across centuries. From its beginnings as a simple wooden frame to today's sophisticated electronic weaving machines, the loom has undergone continual transformation, each stage expanding the creative and structural possibilities of fabric construction. Landmark developments, such as the power loom and the mill system of the Industrial Revolution, revolutionised textile production by enabling mass manufacture and the creation of complex, decorative fabrics like brocades (Buckley & Boudot, 2017). This historical trajectory illustrates how technological advancement, cultural exchange (Chervyakov, 2023), and innovative practice have consistently redefined the global textile industry, while traditional weaving methods continue to find relevance in modern contexts, including interior textile applications (Buckley & Boudot, 2017).

A central determinant of woven fabric complexity lies in the number of shafts a loom possesses, as this directly governs the range of weave structures achievable. Historical precedents such as the Han Dynasty pattern loom highlight the longstanding recognition of shaft capacity as a critical factor in textile innovation (Kumpikaitė et al., 2015). An increased number of shafts permits a broader spectrum of weave patterns, including advanced twills and satins that require more than the basic four shafts typically available (Fazeli et al., 2016; Mamdouh et al., 2022). Such capabilities are essential for producing textiles with distinctive textures and enhanced aesthetic appeal in contemporary design and global markets.

Yet, in resource-constrained environments, many small-scale weaving industries and educational institutions face significant limitations in accessing advanced multi-shaft looms. Ghana is highlighted here as one illustrative example, but similar limitations may have been documented in diverse regions, including parts of India, Nigeria, and other developing economies. A conventional 4-shaft broadloom, while adequate for basic weaves and simple twills, cannot accommodate the complex structures demanded by contemporary markets. This technological limitation restricts weavers' capacity for innovation and diminishes competitiveness against industrial-scale production (Shenton, 2014; Basitha et al., 2022; Kumar & Singh, 2022). Consequently, artisans and students are often confined to simpler weave structures, hindering creative exploration, product diversity, and the development of high-value textiles.

The necessity of the following literature review is therefore to establish the historical and technical context that explains why increasing shaft capacity remains a critical pathway for innovation in small-scale weaving. This review also identifies the knowledge gaps that justify the current investigation into low-cost mechanical modifications as a means of expanding weave complexity. This study responds to these challenges by introducing a design innovation that transforms an existing 4-shaft broadloom into an 8-shaft system. Implemented through locally feasible mechanical adaptations, the modification doubles shaft capacity and enables the production of complex woven structures such as huck-a-back, honeycomb, mock leno, and advanced twill derivatives. Beyond expanding structural and design capacity, this innovation represents a sustainable intervention, as it extends the functional life of existing looms, reduces dependence on costly imports, and fosters grassroots innovation within the textile education and artisanal practice sectors. In doing so, the study contributes to global discourses on sustainable textile development, appropriate technology, and circular design.

This paper documents the transformation process, evaluates the functional performance of the modified loom, and discusses its wider implications for weaving education, artisan livelihoods, and sustainable innovation in the textile sector. Accordingly, this study addressed the following research question: Can a conventional 4-shaft broadloom be retrofitted into an 8-shaft configuration using locally available materials and methods to produce structurally stable complex woven fabrics?

2. Literature Review

This section examines the evolution of loom technology and the pivotal role of shaft mechanisms in shaping woven fabric complexity. It highlights how increasing the number of shafts expands design versatility, enabling the creation of intricate structures such as twills, honeycomb, and huck-a-back. The review also identifies persistent challenges faced by small-scale weavers and educational institutions, particularly in resource-constrained contexts, where access to advanced multi-shaft looms remains limited. In response, the literature emphasises design-led mechanical innovations as practical solutions, underscoring their implications for enhancing textile education, fostering creativity, and promoting sustainable weaving practices.

2.1 Evolution of Loom Technology

Loom technology has undergone a profound transformation, evolving from simple hand-operated frames to today's computerised weaving systems. This progression reflects both technological innovation and the cross-cultural exchanges that have historically shaped textile practices. Early looms, such as wooden frame devices used in Greek tapestry and Navajo blanket weaving, demonstrate the fundamental principles of interlacement (Benson & Warburton, 1986). Archaeological evidence from second-century BCE China, however, reveals advanced pattern looms capable of producing complex structures, challenging assumptions that sophisticated weaving developed only in later periods (Zhao et al., 2016). Similarly, India's ancient handloom tradition illustrates the cultural depth of weaving, though it was severely disrupted during the colonial influx of factory-made textiles (Martins, 2017).

The Industrial Revolution marked a pivotal shift, introducing mechanised looms that increased efficiency and enabled large-scale textile production. The power loom facilitated mass manufacturing, while the Jacquard mechanism automated intricate pattern weaving, revolutionising decorative textile production (Eroğlu & Orbak, 2019). By the twentieth century, electronic and computer-controlled looms further enhanced precision and expanded structural possibilities (Dionisio et al., 2020). These advances were not purely mechanical: they also reflected processes of cultural adaptation, with weaving techniques continually crossing boundaries and being reshaped by local traditions (Faruque & Islam, 2021).

Despite the dominance of industrial machines, traditional weaving practices remain highly valued, particularly for their artisanal craftsmanship, which modern technology often struggles to replicate (Benson & Warburton, 1986). Contemporary textile production increasingly integrates these heritage techniques with modern innovations, seeking to balance efficiency with cultural preservation. From draw looms and Jacquard systems to today's shaft-based mechanisms, each development has progressively expanded weaving capacity (Kumpikaitė et al., 2015). As Fazeli et al. (2016) note, the number of shafts became a decisive factor in determining structural possibilities, enabling satins, twills, and even double cloths.

Scholars have emphasised that loom evolution is not merely technological but also cultural. For instance, traditional weaving practices embedded in communities often relied on looms adapted to local materials and design philosophies, demonstrating that loom design and cultural heritage are inseparable (Lin et al., 2022). However, despite the long history of loom adaptation, the capacity to produce intricate structures has often remained restricted to large-scale or industrial contexts. This historical progression underscores that shaft development remains central to weaving innovation, and small-scale looms have frequently lagged in technological upgrades compared to industrial counterparts.

The historical trajectory of loom evolution thus emphasises a central principle: technological change continually expands creative potential, yet traditional knowledge retains enduring relevance. This duality sets the stage for understanding the role of shaft mechanisms in defining weave complexity, which is explored in the following section.

2.2 Importance of Shaft Number in Weave Complexity

The number of shafts in a loom is a fundamental determinant of its complexity and design capability, as it governs the independently controllable warp threads and thereby shapes achievable weave structures. Even on basic two-shaft looms, techniques such as duotone checkerboards can produce visually intricate effects (Ahmed, 2014). However, loom sophistication generally increases with shaft count, expanding both structural and aesthetic possibilities.

Research demonstrates that shaft number influences not only fabric design but also craft specialisation and labour organisation within weaving cultures (O'Brian, 1999; He & He, 2017). From a technical standpoint, additional shafts enhance flexibility in interlacement, facilitating the production of textiles with both functional diversity and aesthetic refinement (Sychugov, 2022; Fazeli et al., 2016). For instance, Ahiabor et al. (2018) reported that integrating an auxiliary shaft into a four-shaft broadloom enabled the weaving of heavier plain and twill fabrics. While four-shaft looms have historically been the most common, enabling production of plain, twill, and some satin structures, scholars show that higher shaft numbers exponentially expand design options. For instance, Başaran and Bekiroğlu (2023) demonstrate that strategic lift sequencing on four-shaft looms can extend their functional limits, allowing the production of herringbone, pointed, and diamond patterns. However, such ingenuity highlights a paradox: while creativity can maximise existing tools, it cannot substitute for the structural flexibility inherently provided by additional shafts (Mamdouh et al., 2022).

Innovations in shedding mechanisms further demonstrate how shaft design supports complexity. Lin (2023) notes that open-type heald systems simplify pattern creation and improve warp shedding, while Vidgedor et al. (2024) highlight how retrofitted shedding mechanisms can enhance efficiency and design flexibility without abandoning cultural traditions. These examples illustrate how shaft technology both responds to market demands and sustains heritage weaving practices.

Nevertheless, increasing shaft numbers is not without trade-offs. Overly complex configurations may lead to higher costs (Akinwonmi, 2011) or mechanical challenges in hand-operated looms (Ganesan et al., 2019). While higher shaft counts expand design possibilities, loom manufacturers and users must balance technical sophistication with economic viability and practical usability.

Thus, shaft mechanisms represent both a practical and symbolic threshold. They are practical in defining fabric structures and symbolic in reflecting the technological readiness of weaving communities. The reliance on low-shaft looms in many regions illustrates a tension between cultural continuity and technical limitation, a gap that continues to inspire research into adaptive design strategies.

2.3 Technological Constraints in Traditional and Small-Scale Weaving

Technological limitations remain one of the most persistent barriers to the advancement and sustainability of traditional and small-scale weaving industries. These constraints are typically rooted in restricted access to modern equipment, inadequate technical expertise, limited financial resources, and socio-economic challenges that make the adoption of innovation difficult.

Empirical studies consistently show that education and skill gaps significantly hinder the integration of modern weaving practices. For instance, in south-western Nigeria, 58% of weavers lacked technical skills and 87% lacked formal education, which constrained their ability to adopt modern weaving technologies (Dimitrovski et al., 2007). Similar challenges have been documented in Bhagalpur, India, and among Kente weavers in Ghana, where age and low literacy levels further obstruct innovation (Adegbite et al., 2011; Kumar & Singh, 2022). These constraints not only limit technical capacity but also slow intergenerational knowledge transfer, leaving weaving communities vulnerable to technological stagnation.

In addition to education and training gaps, infrastructural and economic barriers further undermine productivity. Small-scale weavers often struggle with inadequate weaving facilities, poor access to quality raw materials, and competition from technologically advanced power looms (Olive et al., 2021; Malarkodi et al., 2020; Divyanshi et al., 2022). The COVID-19 pandemic exacerbated these vulnerabilities by disrupting supply chains and reducing market access (Divyanshi et al., 2022). Recent studies further emphasise that older and less-educated artisans face heightened difficulty in adopting modern weaving technologies, even when available (King et al., 2023).

These multifaceted challenges are compounded by weak institutional support, ineffective government policies, and exploitative marketing practices dominated by middlemen, all of which reduce the profitability and resilience of weaving enterprises (Olive et al., 2021). As a result, many traditional looms remain structurally limited, unable to produce complex designs or diversify product lines due to the high costs, infrastructural deficits, and training barriers associated with accessing advanced looms (Kumar & Singh, 2022). Consequently, the lack of technological adaptability significantly restricts creative innovation and market competitiveness in small-scale weaving industries (Shenton, 2014; Basitha et al., 2022).

These findings highlight a systemic challenge: while industrial weaving advances rapidly, artisanal and small-scale weaving stagnates technologically. Importantly, these studies identify the problem but rarely propose cost-effective mechanical modifications as a solution. This omission is significant because low-cost retrofitting could bridge the divide between tradition and modernity without requiring prohibitively expensive equipment.

2.4 Design Innovation as a Bridge to Sustainable Textile Development

Design innovation plays a critical role in advancing appropriate technology (AT) by offering sustainable, culturally relevant, and economically feasible solutions tailored to local needs. In the context of weaving, such innovation not only enhances productivity and efficiency but also fosters long-term community empowerment and resilience.

Appropriate technology emphasises cost-effectiveness, local adaptability, and social relevance, ensuring that innovations align with the specific cultural and environmental conditions of the communities they serve (Patnaik & Bhowmick, 2018). Within textile design, this approach often involves modifying existing looms to enhance functionality without requiring costly or complex machinery (Pearce, 2012; Patnaik & Bhowmick, 2018). Simple interventions, such as the addition of extra shafts to a basic loom, exemplify frugal engineering, a method of creating practical, low-cost innovations that expand creative possibilities while remaining accessible.

Grassroots innovations are particularly powerful in this regard. They empower local communities to improve tools and processes, leading to greater productivity, expanded design outcomes, and democratized access to advanced textile techniques (Bapat et al., 2023). In educational and small-scale production contexts, such innovations are essential in bridging the gap between traditional handweaving and modern design expectations. Design thinking further strengthens this process by equipping local innovators to generate solutions tailored to their immediate challenges, such as increasing loom efficiency or expanding weave complexity through simple structural modifications (Deyana et al., 2020). For example, Ahiabor et al. (2018) demonstrated this principle by designing and constructing a broadloom capable of weaving compound structures, thereby advancing the scope of handloom-woven textiles.

However, integrating design innovation into AT is not without challenges. Its success depends on the availability of local resources, technical expertise, and stakeholder participation. Moreover, for such innovations to achieve sustainable impact, they must be sensitive to cultural, economic, and political contexts. When effectively implemented, design innovation functions as a bridge between tradition and modernity, enabling sustainable textile development that is locally grounded yet globally relevant.

2.5 Loom Retrofitting: Implications for Education and Sustainable Textile Practice

Hands-on loom modification in textile education fosters experiential learning, critical thinking, and problem-solving, enabling students to engage deeply with the mechanics of weave structures. Through prototyping and experimentation, learners bridge theory and practice, gaining skills that enhance their employability in the evolving textile industry (Örnekoğlu et al., 2022; Xie, 2022). This approach aligns with broader educational goals that emphasise practical competence and design thinking as essential for innovation.

Moreover, loom retrofitting aligns with global calls for sustainable textile production. Rather than discarding existing looms in favour of industrial imports, adapting current infrastructure reduces material waste, promotes affordability, and enhances local capacity (Islam et al., 2022; Congcong et al., 2021). Scholars emphasise that sustainability in weaving must go beyond materials to include the tools and methods themselves. Retrofitting embodies this approach by enabling weavers to innovate within their economic means. In cultural contexts such as Atayal weaving, integrating retrofit strategies has been shown to preserve heritage while fostering sustainable development through education (Shafie et al., 2021). Thus, loom modification functions as a dual strategy, supporting ecological responsibility while reinforcing cultural continuity.

Despite these benefits, retrofitting faces notable challenges. Initial costs, technical expertise requirements, and uneven access to appropriate materials can hinder adoption, particularly in resource-constrained contexts. Furthermore, the effectiveness of retrofitting in meeting sustainability goals depends significantly on the technologies employed, local skills, and institutional support structures.

This literature highlights the importance of shaft mechanisms for enabling complex woven structures and places of interest in design innovation as a means of overcoming technological limitations. Nevertheless, research on loom retrofitting remains scarce, with most studies either focusing on cultural preservation, the limitations of traditional looms or industrial-scale innovation. This leaves a methodological gap where practical, grassroots-level solutions, such as adding shafts to traditional looms, are rarely documented or systematically evaluated. It is within this gap that the present study situates itself, aiming to demonstrate how low-cost modifications can generate structurally diverse fabrics while strengthening the sustainability and relevance of small-scale weaving.

3. Methodology

The methodology centres on transforming a 4-shaft loom into an 8-shaft configuration and assessing its technical performance, sustainability, and educational value. Through systematic modifications, sample weaving, and participant involvement, the study aims to demonstrate how design innovation can improve both the versatility of handlooms and the pedagogical experience in textile education.

3.1 Research Design

This study adopted a practice-based design research approach, guided by the Double Diamond Model of design (Spruce, 2021), which structures inquiry into four iterative phases: Discover, Define, Develop, and Deliver. In industrial design, this model has been shown to streamline processes by balancing divergent and convergent thinking, thereby enhancing efficiency and problem-solving (Saad et al., 2020). Within this framework, creative making functioned simultaneously as both process and inquiry, enabling reflective cycles of exploration, prototyping, and refinement. The double diamond design thinking model adopted for this study is shown in Figure 1.

Figure 1. Double Diamond Design Thinking Model
(Dwass, 2023)

The Double Diamond was selected because its iterative cycles of divergence and convergence complement practice-based research, allowing reflective prototyping and systematic evaluation of design interventions. This makes it particularly suitable for mechanical retrofitting, where solutions must be developed through iterative making and tested against functional performance.

In the Discover phase, the study identified the limitations of a 4-shaft broadloom in producing complex weave structures, drawing on literature and practical observations and highlighted the need for affordable modification strategies. The Define phase articulated the design challenge of converting a 4-shaft broadloom into an 8-shaft configuration to expand pattern versatility while maintaining accessibility in textile education.

During the Develop phase, possible solutions were ideated and prototyped, with the loom retrofitted from a 4-shaft to an 8-shaft configuration as the central experimental intervention. Technical feasibility was assessed through iterative adjustments and testing. Finally, in the Deliver phase, the modified loom was validated through sample weaving exercises, which generated functional textiles and provided reflective insights into design innovation, sustainability, and pedagogical impact.

As Gaver et al. (2022) highlight, practice-based research is inherently iterative, requiring cycles of reflection and adaptation that foster both innovation and knowledge production. Felix (2022) cautions, however, that maintaining scholarly rigour in such fluid processes is a challenge. To address this, the study integrated design-thinking principles (de Laat and Marten, 2019; Nanda and Wingler, 2020) as a structured yet flexible framework for problem-solving and innovation.

This design model was therefore well-suited for balancing systematic inquiry with creative exploration, generating both functional outcomes and reflective insights into design innovation, sustainability, and textile education.

3.2 Tools, Materials and Equipment

A standard 4-shaft broadloom was used as the base equipment. Additional pulleys, horses, shafts, lams, cords, treadles, and mechanical fittings were sourced locally for the modification. Weft yarns of cotton and polyester were employed in sample weaving to test different weave structures. Documentation tools included sketchbooks, cameras, and note-taking for recording the process.
Tools are lightweight, manual equipment designed for specific tasks, requiring human effort and precision for efficiency and effectiveness, which are essential for construction and repair work (Industrial Mega Mart, 2024). The tools in Figure 2 were used in the retrofitting of the 4-shaft broadloom.

Figure 2. a) Drilling machine, b) Hacksaw, c) Clamp, d) Tape measure, e) Chisel, f) Hammer

According to Habibov (2023), materials are the substances or components that are processed or transformed during manufacturing or construction. In the context of retrofitting the 4-shaft loom, Figure 3 exhibits the materials used during the process.

Figure 3. a) Odum wood, b) Metal bars, c) Bolts and nuts, d) Cotton cords

Again, Habibov (2023) highlight that equipment encompasses machinery and tools used to perform tasks or processes. The 4-shaft broadloom was the machine used in weaving fabrics and had to be modified into an 8-shaft system for complex structures. The 4-shaft broadloom is shown in Figure 4.

Figure 4. A 4-shaft Broadloom
(Source: Textile Weaving Shed – KNUST, 2025)

3.3 Loom Modification Procedure

The modification followed an iterative design process:

3.3.1 Design and Planning – Technical adjustments were first sketched to guide the conversion of a 4-shaft loom into an 8-shaft configuration. The original loom comprised 2 pulleys, 4 horses, 4 shafts, 4 lams, and 6 treadles, forming the vertical connection responsible for the shedding mechanism. In this setup, 2 treadles controlled the plain weave while the remaining 4 were used for twill designs.

The main objective was to transform this 4-shaft system into an 8-shaft mechanism by doubling the vertical connections. This required expanding the loom structure to include 4 pulleys supporting 8 horses, which were connected to 8 shafts via 8 lams. These were then tied to 8 design treadles and 2 plain treadles, making a total of 10 treadles. This new configuration provided the technical framework for upgrading the 4-shaft broadloom to an 8-shaft broadloom. Figure 5 illustrates the transformation between the shedding mechanisms of the two systems.

Figure 5. Technical transformation of the shedding mechanism between a 4-shaft and an 8-shaft broadloom.

3.3.2 Construction and Retrofitting **–** Based on the technical plan, additional wooden components (pulleys, lams, and treadles) were fabricated to match the existing loom dimensions and maintain structural balance. The new horses and shafts were integrated into the frame, ensuring alignment with the original shedding system. All moving parts were reinforced to withstand increased mechanical tension during weaving. These ideas were engineered on paper to be constructed into various parts for assembly and adjustment.

Figure 6. a) Pulleys, b) Horses, c) Shafts (with healds), d) Lams, e) Treadles

3.3.3 Assembly and Adjustment **–** The expanded shedding system was installed, connecting pulleys to horses and to shafts via lams to treadles. Careful adjustments were made to ensure even tension distribution and precise shaft movement. The treadles were tied up according to planned weave sequences, allowing both plain weave and complex patterned designs to be produced.

Figure 7. Connecting and adjusting the shedding mechanism of the 8-shaft broadloom

Adjustments were made to reduce friction, balance treadle pressure, and enhance the responsiveness of shaft lifting. Successful operation of all 10 treadles confirmed the feasibility of the 8-shaft conversion. The retrofitted 8-shaft broadloom after final assembly and inspection is shown in Figure 8.

Figure 8. The Retrofitted 8-shaft broadloom

3.4 Production of Fancy Weaves with Retrofitted 8-Shaft Broadloom

Following the adjustments and preliminary trials, the modified loom was evaluated through the production of complex weave structures, specifically huck-a-back and honeycomb. These designs were selected to test the loom's capacity for clarity, structural stability, and overall technical feasibility. The weaving process was undertaken in two stages: warp preparation and weft preparation, which are detailed in Sections 3.4.1 and 3.4.2.

3.4.1 Warp Preparatory Processes

Under warp preparation, the following processes were executed sequentially to complete the warp preparatory processes. Figure 9 outlines the respective processes of warp preparation in the study.

Figure 9. Warp Preparatory Processes

It was essential to construct the weave structures to examine the relationship among their core elements: design, draft, tie-up, and treadling order. For this purpose, WeavePoint software was employed to develop huck-a-back and honeycomb weaves, generating their respective design parameters. The resulting structures are presented in Figure 10.

Figure 10. a) Huck-a-back design, b) Honeycomb design

The warp ends were calculated to ensure equal distribution of colour patterns across the respective weave designs. Shrinkage was factored in as a critical element affecting the final fabric width, alongside reed size and intended woven width. The calculation followed the formula:

No. of ends = (width of fabric x reed size) + (2 x Selvedge)
No. of ends = (34 inches x 32-inch reed) + (2 x 32)
No. of ends = 1088 + 64
No. of ends = 1152 ends

Based on this total, warp colours were distributed evenly according to yarn thickness and colour sequence. The design process also considered principles of balance and harmony to achieve aesthetically coherent arrangements. The final warp colour plan, detailing the number of yarns per colour in each repeat, is presented in Table 1.

Table 1. A Table Showing Warp-End-Colour Distribution Pattern of Weaves

After determining the total number of warp ends required for the woven fabrics, milling was undertaken. Cotton spun yarns were wound on a warping mill to establish both warp length and the necessary crosses for shed formation during weaving. The calculated warp colour ends were counted in orderly succession to complete the total ends of each weave design. Following milling, the warp was removed by chaining, a process that secures the long warp length and prepares it for subsequent raddling and beaming.

At the raddling stage, warp ends were distributed evenly into the raddle dents based on the reed size - 32. During this process, 16 ends were inserted per 2 raddle dents to correspond to one inch of reed width. The warp was then stretched under tension with the drag box to bring the crosses forward. Parallel orientation of warp ends was checked, and any entanglement or loose ends were corrected to ensure uniform tension across the warp during winding onto the warp beam. Beam sticks were inserted to separate layers, facilitating smooth let-off during weaving.

Heddling followed, where individual warp ends were drawn through the heald eyes of the shafts according to the respective weave drafts generated in WeavePoint. This order of threading, known as the heddling order, for the Huck-a-back and Honeycomb structures, is illustrated in Figures 11 and 12.

/1,2,1,2,1/3,4,3,4,3/5,6,5,6,5/7,8,7,8,7/

Figure 11. Heddling order of Huck-a-back

/1,2,3,4,5,6,7,8/7,6,5,4,3,2/

Figure 12. Heddling order of Honeycomb

The next step, reeding, involved passing the heddled warp ends through the reed dents. Doubling was applied only at the fabric selvedges to reinforce and produce neat woven edges.

Subsequently, the shafts were tied through the lams to their corresponding treadles, while the reeded warp ends were fastened to the cloth beam. This ensured correct design execution during weaving, as each treadle depression simultaneously lowered the connected shafts to form the shed. The tie-up structures are shown in Figures 13 and 14, and their numerical representations are summarised in Table 2.

Figure 13. Huck-a-back tie-up arrangement

Figure 14. Honeycomb tie-up arrangement

Table 2. A table showing the Tie-up Arrangements of Shafts to Treadles

The stepping orders employed were as follows:
Huck-a-back: /1,2,1,2,1/3,4,3,4,3/5,6,5,6,5/7,8,7,8,7/
Honeycomb: /1,2,3,4,5,6,7,8/7,6,5,4,3,2/

These stepping orders indicate the numerical sequence of treadle operation, whereby depressing a treadle lowers the connected shafts, leaving others raised, thereby creating the shed for weft insertion and beat-up. These cycles, repeated continuously, constituted the primary motions of weaving until the desired fabric length was achieved.

Finally, tying the warp yarns to the cloth beam secured the uniform tension necessary for consistent shed formation. Warp ends were tied in groups against the apron stick attached to the cloth beam, completing the warp preparation for weaving. The warp preparation processes are exhibited in Figure 15.

Figure 15. a) Milling, b) Chaining, c) Raddling, d) Beaming (Completed), e) Heddling, f) Denting/Reeding, g) Lam-treadle tie-up, h) Warp ends-cloth beam tie-up

3.4.2 Weft Preparatory Processes

The preparation of the weft yarns was essential to ensure smooth insertion during weaving and to achieve a uniform fabric appearance and structural stability. The processes involved winding weft yarns onto bobbins and shuttle loading. The yarns were wound onto pirns or bobbins using a bobbin winder. This process ensured that the yarn was tightly and uniformly packed, thereby allowing smooth release within the shuttle during weft insertion. Care was taken to maintain consistent yarn tension to avoid loose or overly stretched sections, which could compromise fabric uniformity. The wound bobbins were then placed inside shuttles, ensuring proper alignment to enable free yarn delivery. The shuttle eye was checked to confirm that the yarn could unwind without obstruction. Multiple bobbins were prepared in advance to ensure efficiency and continuity during weaving.

Where coloured yarns were employed, the sequence of bobbin preparation followed the predetermined design plan to maintain colour order and achieve harmony in the woven pattern. The consistency in weft colour changes complemented the warp arrangement, thereby enhancing the aesthetic quality of the final fabric.

Figure 16. A Tested Weave or Trial Weave Picks

Before commencing weaving, trial picks were inserted to test the free flow of the weft yarn from the shuttle and to confirm the absence of weak spots, knots, or tension irregularities. This is shown in Figure 16. Only after satisfactory performance was established were the prepared weft yarns used in weaving the Huck-a-back and Honeycomb structures.

3.4.3 Final Woven Fabrics

After completing the weaving processes, the woven fabrics produced on the retrofitted 8-shaft broadloom represented the practical realisation of the Huck-a-back and Honeycomb weave structures. The final woven samples reflected the efficiency of the modified shedding mechanism as well as the accuracy of the preparatory processes.

The Huck-a-back fabric exhibited clearly defined floats and cell-like textures characteristic of the structure, while the Honeycomb fabric showed the three-dimensional cellular effects that give the weave its depth and geometric appearance. Objective examination showed that the woven samples maintained uniform warp tension across the width (variation within ±2 mm), no skipped threads were detected in lengths exceeding 1 metre, and float lengths remained consistent with the planned drafts. These indicators demonstrate that the fabrics were structurally sound under the trial weaving conditions.

Figure 17. Huck-a-back woven fabric

Figure 18. Honeycomb woven fabric

From an aesthetic perspective, the planned warp and weft colour distributions achieved harmony and balance in the woven samples. The interplay of colour and weave structures created fabrics that were both visually appealing and technically sound. Selvedges were firm due to the doubled warp threads at the edges, which enhanced neatness and durability. While these outcomes indicate the operational stability of the retrofit under trial conditions, further work is required to assess long-term durability, scalability, and efficiency under continuous production.

Although the present study focused on the retrofitting and operation of an 8-shaft broadloom, it is important to situate these findings within the broader context of conventional 4-shaft looms commonly used in textile training and small-scale weaving. The 4-shaft loom, while widely accessible, is limited to basic weaves such as plain, twill, and basket designs. In contrast, the retrofitted 8-shaft broadloom employed in this study significantly expands the design scope, enabling the successful production of more complex structures like huck-a-back and honeycomb. This functional shift underscores the technical and creative advantages of retrofitting, even though a direct experimental comparison was beyond the scope of this work. To illustrate the distinction,

Table 3 provides a conceptual summary of the main differences between 4-shaft and 8-shaft loom capacities, as reflected in both literature and practice.

Table 3. Conceptual Comparison between Conventional 4-Shaft Loom and Retrofitted 8-Shaft Broadloom

4. Discussion

This section interprets the findings of the study in relation to the objectives and existing literature. While the preceding sections focused on the technical processes and outcomes of modifying a 4-shaft loom into an 8-shaft configuration, the discussion highlights the significance of these outcomes for weaving practice, textile education, and sustainable design innovation.

The successful retrofit of doubling pulleys, horses, shafts, lams, and treadles to achieve coordinated 8-shaft shedding demonstrates that appropriate, low-cost design interventions can extend the capability of existing looms. In practical terms, this marks a significant step beyond the baseline 4-shaft system, which is structurally constrained to plain, twill, and other fundamental weaves. By contrast, the retrofitted 8-shaft configuration unlocks a wider repertoire of interlacements and float manipulations, situating the loom within a higher functional class while retaining affordability and serviceability. This aligns with appropriate technology principles that prioritise locally serviceable, cost-effective solutions (Pearce, 2012; Patnaik & Bhowmick, 2018) and responds to the access constraints documented in small-scale and educational contexts (Kumar & Singh, 2022; Shenton, 2014; Basitha et al., 2022). Methodologically, the iterative diagnose–prototype–adjust cycle reflects the Double Diamond's structured divergence/convergence and supports disciplined rigour within practice-based inquiry (Spruce, 2021; Saad et al., 2020; Gaver et al., 2022; Felix, 2022; de Laat & Marten, 2019; Nanda & Wingler, 2020). Prior work similarly shows that added shaft capacity or auxiliary mechanisms enable more demanding constructions (Ahiabor et al., 2018).

Fabric trials of huck-a-back and honeycomb weaves exhibited clear pattern definition and structural stability, consistent with the established relationship between shaft number and weave complexity: additional shafts expand the set of possible interlacements and float paths (Fazeli et al., 2016; Mamdouh et al., 2022; Kumpikaitė et al., 2015). While four shafts can accommodate limited patterning through careful lift sequencing (Başaran & Bekiroğlu, 2023), such attempts often compromise clarity and motif stability. In this study, the 8-shaft retrofit achieved distinct cellular and geometric effects with improved dimensionality, affirming the comparative advantage of extended shaft capacity as opined by (Mamdouh et al., 2022; Fazeli et al., 2016). The study's incremental tie-up and treadling refinements reflect best-practice optimisation of shedding efficiency (Lin, 2023; Vidgedor et al., 2024). Minor operational challenges, such as balancing tensions across added shafts, are typical of hand-loom adaptations and are addressable through iterative adjustment, as cautioned in studies on hand-loom mechanics (Ganesan et al., 2019).

Positioning the retrofit within practice-based research allowed making to serve as both method and evidence, deepening understanding of structure–mechanism relationships (Gaver et al., 2022; Felix, 2022). In educational settings, this shift from a 4-shaft to an 8-shaft reinforces the pedagogical trajectory from foundational weave knowledge toward advanced structural design. The retrofit, therefore, not only broadens technical capability but also strengthens experiential learning, problem-solving, and employability-relevant competencies (Örnekoğlu et al., 2022; Xie, 2022). By enabling complex structures on affordable equipment, the retrofit grants access to advanced weave explorations otherwise limited by cost and infrastructure (Kumar & Singh, 2022; Shenton, 2014; Basitha et al., 2022).

Retrofitting an existing 4-shaft loom rather than procuring a new machine advances resource efficiency and equipment life-extension, echoing sustainability gains identified for retrofitting in textile contexts (Islam et al., 2022; Congcong et al., 2021; Shafie et al., 2021). As grassroots innovation, the modification leverages local materials and skills, reinforcing frugal, context-responsive design (Bapat et al., 2023; Deyana et al., 2020) and the broader Appropriate Technology agenda (Pearce, 2012; Patnaik & Bhowmick, 2018). In regions where supply chains, skills, and finance constrain technology adoption (Adegbite et al., 2011; Divyanshi et al., 2022; Malarkodi et al., 2020; King et al., 2023), such interventions provide practical, scalable pathways to raise design capacity while sustaining cultural weaving practices (Faruque & Islam, 2021; Vidgedor et al., 2024).

For small-scale and cottage industries, the retrofit presents a replicable route to diversify products with higher value-added structures using existing infrastructure (Kumar & Singh, 2022; Shenton, 2014). Economically, design choices must continue to balance complexity with practicality, mindful of cost and maintenance trade-offs (Akinwonmi, 2011; Ganesan et al., 2019). Future work could examine durability and throughput under extended use, explore further shaft expansion (e.g., toward double-cloth or satin derivatives noted in the shaft-complexity literature), and integrate digital drafting workflows more systematically (Fazeli et al., 2016; Mamdouh et al., 2022; Eroğlu & Orbak, 2019). Such trajectories would continue bridging traditional craftsmanship with modern design capability, a theme running through historical and contemporary loom development (Benson & Warburton, 1986; Kumpikaitė et al., 2015; Eroğlu & Orbak, 2019; Dionisio et al., 2020).

The design interventions, sketching, iterative shaft additions, tie-up refinements, and systematic adjustments directly yielded the functional 8-shaft configuration validated through the production of huck-a-back and honeycomb fabrics. This clear sequence from design ideation to woven samples demonstrates how the design process informed and shaped the outcomes. Thus, the conclusions drawn are grounded in the tested artefacts and their observed performance rather than assumptions.

5. Conclusion

This study investigated the feasibility and implications of retrofitting a 4-shaft broadloom into an 8-shaft system to enable the production of complex weave structures such as huck-a-back and honeycomb. Using a practice-based design approach guided by the Double Diamond framework, the research demonstrated that systematic inquiry through making can deliver both functional innovation and academic insight.

The findings indicate that the retrofit was technically feasible and operationally stable under trial conditions, producing structurally sound fabrics with enhanced pattern definition. While the original 4-shaft system limited weavers to plain weaves and simple twills, the expanded 8-shaft configuration enabled more diverse weave structures, thereby affirming the well-established relationship between shaft capacity and structural complexity.

The broader significance of this work lies in its alignment with principles of sustainability and appropriate technology. By extending the lifespan and capacity of existing equipment, the retrofit offers a low-cost, locally serviceable alternative to imported multi-shaft looms. This contributes to circular design practices, reduces technological dependence, and enhances local capacity for innovation. In educational settings, the modification broadens opportunities for experiential learning in complex weave design, fostering problem-solving skills and creative exploration essential for textile and design education.

While initial trials show promising results, the study acknowledges that long-term durability, efficiency under extended use, and scalability require further investigation. These limitations suggest a cautious interpretation of the findings as evidence of feasibility rather than definitive proof of universal success.

References

Adegbite, S. A., Ilori, M. O., and Aderemi, H. O. (2011). Innovations in the Indigenous Textile Weaving Firms in Southwestern Nigeria. The International Journal of Business and Management, 6(12), 243. https://doi.org/10.5539/IJBM.V6N12P243

Ahiabor, R., Awuyah, I. R., and Nyante, B. (2018). Design and construction of a broadloom capable of weaving compound weaves. Arts and Design Studies, 63, 1-13.

Ahmed, A. G. M. (2014). Modular Duotone Weaving Design. 27–34. http://archive.bridgesmathart.org/2014/bridges2014-27.pdf

Akinwonmi, A. S. (2011). Design and Construction of a Mechanised Loom. http://www.maxwellsci.com/print/rjaset/v3-159-171.pdf

Bapat, S., Fischer, L., and Malshe, A. P. (2023). Understanding Frugal Engineering Process for Frugal Innovations: Socially Conscious Designs for Homeless Individuals, A Case Study. Procedia CIRP, 119, 266–271. https://doi.org/10.1016/j.procir.2023.03.097

Başaran, F. N., and Bekiroğlu, E. (2023). Study on the alternative weaving patterns on four-shaft looms. Zeitschrift Für Die Welt Der Türken, 15(2), 181–204. https://doi.org/10.46291/zfwt/150213

Basitha, T. N., Affrilyno, A., and Zain, Z. (2022). Pengembangan kawasan rumah tenun sambas di desa sumber harapan kabupaten sambas. Jurnal Mosaik Arsitektur, 10(2), 339. https://doi.org/10.26418/jmars.v10i2.53906

Benson, A., and Warburton, N. (1986). Looms and weaving. Shire Publications. http://ci.nii.ac.jp/ncid/BB00930965

Buckley, C. D., and Boudot, E. (2017). The evolution of an ancient technology. Royal Society Open Science, 4(5), 170208. https://doi.org/10.1098/RSOS.170208

Buckley, C. D., and Boudot, E. (2017). The evolution of an ancient technology. Royal Society Open Science, 4(5), 170208. https://doi.org/10.1098/RSOS.170208

Chervyakov, V. V. (2023). Pattern Weaving: Cultural Context and Technological Practices. Общество: Философия, История, Культура. https://doi.org/10.24158/fik.2023.12.50

Congcong, P., Boshan, G., and Xinyu, C. (2021). Introduction of the Environmental Protection Concept in Textile Major Education. 5(1), 60–63. https://doi.org/10.26549/JETM.V5I1.6471

de Laat, M., and Martens, R. (2019). Practice-based design research to advance teaching and learning practices through situated partnerships (pp. 147–159). Routledge. https://doi.org/10.4324/9780429275692-9

Deyana, V., Ikhsan, A., and Suryani, E. (2020). Perancangan alat bantu sulaman dengan menggunakan metode design thinking di industri rumah tangga sulaman kapalo samek yusnetti. 16(3). https://www.ejurnal.bunghatta.ac.id/index.php/JFTI/article/view/18148

Dimitrovski, K., Demšar, A., and Rolich, T. (2007). Mass Customisation in Weaving.

Dionisio, R., Malhao, S., and Torres, P. M. B. (2020). Development of a Smart Gateway for a Label Loom Machine using Industrial IoT Technologies. 16(04), 6–14. https://doi.org/10.3991/IJOE.V16I04.11853

Divyanshi, Kumar, S. and Singh, V. (2022). Constraints Faced by Loom Weavers Related to Production and Marketing of Weaved Products in Bhagalpur District of Bihar. Asian Journal of Agricultural Extension, Economics & Sociology. http://doi.org/10.9734/AJAEES/2022/v40i931001

Dwass, S. (2023). The 4 Ds: Double Diamond Design Thinking Model. Available at: https://www.fluxspace.io/resources/the-4-ds-double-diamond-design-thinking-model. Accessed on August 16, 2025.

Emonts, C., Grigat, N., Merkord, F., Vollbrecht, B., Idrissi, A., Sackmann, J., and Gries, T. (2021). Innovation in 3D Braiding Technology and Its Applications. 1(2), 185–205. https://doi.org/10.3390/TEXTILES1020009

Eroğlu, D. Y., and Orbak, âli Y. (2019). Simulated annealing algorithm and implementation software for the fabric cutting problem. Tekstil Ve Konfeksiyon, 30(1), 10–19. https://doi.org/10.32710/TEKSTILVEKONFEKSIYON.521944

Faruque, S., and Islam, B. (2021). Evolution of Handloom Weaving Activity in India. Journal of the University of Shanghai for Science and Technology, 23(09), 1069–1072. https://doi.org/10.51201/JUSST/21/09627

Fazeli, M., Kern, M., Hoffmann, G., and Cherif, C. (2016). Development of three-dimensional profiled woven fabrics on narrow fabric looms. Textile Research Journal, 86(12), 1328–1340. https://doi.org/10.1177/0040517515606361

Felix, S. (2022). Exploring the Transformative Potential of Practice-based Design Research (PBDR) Methods in Architectural Design Pedagogy. https://doi.org/10.54223/10539/35908

Ganesan, S., Ganesan, S., Badari Nath, K., and Badari Nath, K. (2019). Design and Development of Mechanical and Electronic Jacquard Handloom for Fine-Korai-Mat Weaving (pp. 335–346). Springer, Singapore. https://doi.org/10.1007/978-981-13-6435-8_25

Gaver, W., Krogh, P. G., Boucher, A., and Chatting, D. (2022). Emergence as a Feature of Practice-based Design Research. Designing Interactive Systems Conference. https://doi.org/10.1145/3532106.3533524

Habibov, I. (2023). Equipment technologies and materials. https://doi.org/10.5281/zenodo.10335315

He, D., and He, J. (2017). Shaft number-variable robot and control method thereof.

Industrial Mega Mart (2024). Understanding the Difference Between Tools, Equipment, and Machines. Available at: https://medium.com/@pandeyahardikji/understanding-the-difference-between-tools-equipment-and-machines-16c106b3a8a5. Accessed on August 18, 2025.

Islam, Md. T., Jahan, R., Jahan, M., Howlader, Md. S., Islam, R.-U., Islam, Md. M. Hossen, Md. S., Kumar, A., and Robin, A. H. (2022). Sustainable Textile Industry: An Overview. Non-Metallic Material Science, 4(2). https://doi.org/10.30564/nmms.v4i2.4707

King, R. S., Mensah, H., Simpeh, E. K., and Nerquaye-Tetteh, E. (2023). Exploring the Kente weaving industry to drive smart community development in Ghana. SN Social Sciences, 3(12), 205.

Kumar, S., and Singh, V. (2022). Constraints Faced by Loom Weavers Related to Production and Marketing of Weaved Products in Bhagalpur District of Bihar. Asian Journal of Agricultural Extension, Economics and Sociology, 249–253. https://doi.org/10.9734/ajaees/2022/v40i931001

Kumar, S., and Singh, V. (2022). Constraints Faced by Loom Weavers Related to Production and Marketing of Weaved Products in Bhagalpur District of Bihar. Asian Journal of Agricultural Extension, Economics and Sociology, 249–253. https://doi.org/10.9734/ajaees/2022/v40i931001

Kumpikaitė, E., Kot, L., and Vizbaras, M. (2015). Development of a Weaving Method for Spatial Two-Layer Innovative Structure Linen Fabric. Fibres & Textiles in Eastern Europe, 23, 68–71. https://doi.org/10.5604/12303666.1167422

Lin, J.-L. (2023). An Innovative Design for Drawlooms with an Open-Type Heald. https://doi.org/10.3390/engproc2023055036

Lin, R., Chiang, I.-Y., Taru, Y., Gao, Y.-J., Kreifeldt, J. G., Sun, Y., & Wu, J. (2022). Education in Cultural Heritage: A Case Study of Redesigning Atayal Weaving Loom. Education Sciences, 12(12), 872. https://doi.org/10.3390/educsci12120872

Malarkodi, M., Indumathi, V. M., Deepa, N., and Divya, K. (2020). Analysing constraints of handloom weavers in the western zone of Tamil Nadu using the rank-based quotient technique. International Journal of Farm Sciences, 10(3and4), 79-82.

Mamdouh, F., Reda, M. M., El-Aziz, H. A., and Othman, H. (2022). Overview of different fabric structures. Egyptian Journal of Textile and Polymer Science and Technology, 19(2), 291–306. https://doi.org/10.21608/jtcps.2022.152641.1131

Martins, N. C. (2017). Loom: Unifying Client-Side Web Technologies in a Single Programming Language. https://run.unl.pt/bitstream/10362/55173/1/Martins_2017.pdf

Nanda, U., and Wingler, D. (2020). Practice-Based Research Methods and Tools: Introducing the Design Diagnostic. Herd-Health Environments Research & Design Journal, 13(4), 11–26. https://doi.org/10.1177/1937586720945176

O'Brian, R. (1999). Who Weaves and Why? Weaving, Loom Complexity, and Trade. Cross-Cultural Research, 33, 30 - 42.

Olive, P. F., Mahendran, K., Lavanya, S. M., and Devi, H. D. An Empirical Analysis of Constraints Faced by the Handloom Weavers and Weaver Cooperative Societies in Virudhunagar District of Tamil Nadu.

Örnekoğlu, M., Emmanouil, M., Grizioti, M., and Van Langenhove, L. (2022). Using Online Games in Textile Engineering Education. 113, 155–161. https://doi.org/10.4028/p-p79su1

Patnaik, J., and Bhowmick, B. (2018). Appropriate Technology: Revisiting the Movement in Developing Countries for Sustainability. World Academy of Science, Engineering and Technology, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 12(3), 246–250. https://publications.waset.org/10008726/appropriate-technology-revisiting-the-movement-in-developing-countries-for-sustainability

Pearce, J. M. (2012). The case for open source appropriate technology. Environment, Development and Sustainability, 14(3), 425–431. https://doi.org/10.1007/S10668-012-9337-9

Saad, E., Elekyaby, M. S., Ali, E. O., and Hassan, S. F. A. E. (2020). Double diamond strategy saves time in the design process. International Design Journal, 10(3), 211-222.

Shafie, S., Kamis, A., and Ramli, M. F. (2021). Sustainability of Fashion Apparel Toward Environmental Well-Being and Sustainable Development. 4(1), 60–78. https://doi.org/10.12928/JOVES.V4I1.3638

Shenton, J. (2014). Woven Textile Design. https://www.amazon.com/Woven-Textile-Design-Jan-Shenton/dp/178067337X

Spruce, J. (2021). Reflections on a Project-Based Approach to Work-Related Learning in Spatial Design. Design Principles and Practices, International Journal of Design Education, 15(1), 101-117.

Sychugov, A. N. (2022). Evaluation of the Manufacturability of "Shaft"–Type Parts with the Use of Complex Methods. https://doi.org/10.21741/9781644901755-75

Vidgedor, D., Akrofi, M., Bruce-Amartey Jnr, E., and Howard, E.K. (2024). Integration of Counter Shaft Shedding Mechanism into Indigenous Two-Heddle Loom: A Novel Approach. Fashion and Textiles Review.

Xie, B. (2022). Critical thinking and problem solving. ICERI Proceedings. https://doi.org/10.21125/iceri.2022.0986

Zhao, F., Wang, Y., Luo, Q., Long, B., Zhang, B., Xia, Y., and Xie, T. (2016). Mechanism of Laoguanshan Pattern Looms from Late 2nd Century BCE, Chengdu, China (pp. 209–221). Springer, Cham. https://doi.org/10.1007/978-3-319-31184-5_19