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CREATING A PROTOCOL FOR RECONSTRUCTING WEAVING TECHNOLOGIES: EARLY COMPOUND NON-SILK FABRICS FOUND IN EGYPT

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Introduction
The examination of weft-faced compound non-silk fabrics found in Egypt (ca. 3rd - 7th century A.D.), in the Royal Ontario Museum collections, revealed many structural differences and similarities. Single, double and ply yarns with apparent variation in size and set density were observed. Some have their twist in "S" direction, others in "Z" direction, with diverse amount of twist. Wool yarns make up the majority of the constructions, but in many cases wool yarns alternate with cotton and sometimes linen yarns. Tabby and 1/2 twill weaves are employed as binding weaves, while the compound weave structures comprise 1:1 and 2:1 ratios of inner-warp to binding-warp ends. These variations provide a very interesting spectrum of textures executed in varying degrees of design complexity. The existence of many variables creates a necessity to seek a quantitative and systematic methodology, through which identification, classification and interpretation of technical data would be possible.

Reconstruction of weaving technologies has been selected as the principal criterion for the research. It requires analysis which must be detailed enough to determine the technological range of variations, and to indicate how and why weavers of different groups of civilization manipulated their weaving techniques. This paper mainly discusses the aspects considered in developing a protocol which records and confirms objectively the structural and technical parameters of the textiles under study.

1.0.0. The Objective: Concept and Rational
A protocol for reconstructing early weaving technologies should consist of indispensable attributes to impart an integral system, thus elucidating the weaving details and mode of fabrication. It should not be devised for the mere gathering of technical data, but it should enclose a system organizing and employing these data to deal with basic and imperative questions. The data would provide information on what types of material were used; indicate how these materials were assembled in a textile form; and be utilized to explain why materials and processes changed at certain times of history in a certain way, in addition to what can be learned from textiles as to the resources, skills and knowledge of those who made it. Thus, further distinctions of early textiles can be drawn, not only on the basis of elements related to their outer appearance, but also by the indispensable attributes of their inner structures.

In a protocol of such nature, data pertinent to some of
the parameters has to be quantitatively analyzed. To assess this data objectively, it would be unavoidable to apply destructive techniques through conventional routines of textile analysis. However, the value and frail nature of early textiles demand the search for analytical methods, which would be advantageous and compatible to their nature. These requirements initiate the adaptation of non-destructive techniques, and the derivation of information from established knowledge in Textile Science.

This approach has not been generally exploited in the study of textiles in museums' collections. It must be emphasized, however, that this is not by any means an attempt to superficially impose upon the studies to be undertaken in this field, what might be termed, the modern norms of textile industry. Evidently, these "norms" are out of context. There must be a clear understanding and profound discrimination between complying with modern industrial standards, and applying basic knowledge of materials science. Similar approaches have been accepted and established in other disciplines studying the technology of ancient materials.

2.0.0. The Protocol: Components and Construction

Devising the protocol demanded an assimilative method which builds up technical data from inter-related substructural components. Each component consists of selected parameters based on a comprehensive list of priorities. Technological idiosyncrasies affecting the weaving process, assumed top priority. Four substructural components have been identified and incorporated in the protocol: yarn characteristics, fabric construction, weave structure and design. Their organization and constituents are presented in the chart appearing in fig. 1. The following discussion will underline points related to each component. Detailed technical information is beyond the limits of this paper, and can be obtained by referring to the selected bibliography related to the protocol.

2.1.0. Yarn Characteristics:

Because of the absence of selvedges in many of the early specimens, two directions (X) and (Y) are designated as a guide, before determining what is warp and what is weft. It is essential in analyzing woven fabrics to identify separately the characteristics of each set-of elements in both directions. The analysis to be followed is mainly concerned with the structure and dimension details of yarns, the aspects of their physical properties.

2.1.1. Fibre content and treatment: Identification of fibre content can be determined through microscopic examination. Due to the limited types of fibres used in early textiles, their general identification is simplified to a certain extent. For the purpose of categorization, the treatment of the yarns has been considered. The yarn will fall under: untreated, i.e., in natural state; treated, e.g., bleached, sized ... etc; or dyed, in which case the colour should
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be specified.

2.1.2. Yarn construction and twist: It is apparently important to identify the yarn as whether it is single or ply. In single yarns, the twist direction of the attenuated fibres does not affect their mechanical properties, but it can have an effect on fabric design and texture. In the study of early textiles these aspects of yarn construction and twist direction have additional implications, which may point out provenance and cultural contacts. A complete specification of the yarn will, therefore, include data on the direction of twist, either in "S" or "Z" direction, and a quantitative measure of the amount of twist.

Although the amount of twist is usually expressed in number of turns per inch or centimeters, this quantity is insignificant to the characterization of early woven fabrics. Apart from the necessity of unravelling yarns from the fabric to attest the number of turns per unit length, this data is useless in comparing yarns of unequal sizes. What matters is not the number of turns, but the angle of twist. This is the helix angle which fibres on the yarn surface make with the yarn axis; the larger this angle, the harder the twist, fig. 2. Furthermore, this angle is a function of both the twist content (turns per unit length), and the number of fibers per cross-section (yarn size). Hence, twist content alone cannot provide a measure of the twist hardness. The following formula may summarize these relationships:

\[ \tan \Theta = \frac{\pi d}{1/T} = \frac{\pi d}{T} \]

Therefore, \[ T = \frac{\tan \Theta}{\pi d} \]

where: \( T \) = turns/inch; \( d \) = yarn diameter and \( \Theta \) = helix angle

The recording of helix angle has been considered an important factor in studying old fabrics. Bellinger (1) studied over a hundred 16th century Turkish and Venetian velvets and brocades; and found that the warp ends of the Turkish textiles were spun with a helix angle ran between 10°- 15°, whereas their counterpart had a uniform spin of 20°. The question of whether the earlier yarns will show such uniformity was raised, but the answer does not seem to be available because of insufficient systematic and comparative data. This may be also due to the fact that measuring the helix angle is not easy with conventional methods. The measurement is greatly simplified by using a projected structural image of the yarn, and directly determine the angle degree from the image (in the form of a slide ). At least 10 readings are recommended to obtain an average.

2.1.3. Yarn diameter and linear density: Use has been made of calculated value of yarn diameter based on the yarn linear density, for the purpose of systematizing the analysis of cloth geometry (2). The term linear density is used to denote scientifically what is known as yarn "count" or "number". It is a numerical expression which define yarn fineness,
indicating the mass (weight) per unit length. The "tex" unit - grams per kilometer (1000 meter) - has been approved by ISO/TC 38 for use with all types of yarns; and therefore, employed in the protocol. Inevitably, the knowing of yarn linear density becomes a critical factor in the reconstruction process. Determination of the linear density can be calculated by weighing a prescribed, measured length of yarn (3). However, this procedure is obviously destructive, and requires considerable amount of yarns to be removed from the fabric; which cannot be sacrificed or justified for analyzing early textiles. For this reason, an approximation of linear density based on theoretical calculations may be acceptable. Derivation from many established formulae (4) for calculating yarn diameter can be used, such as:

\[ d = 0.0357 \sqrt{V \times t} \]

where: \( d \) = yarn diameter (mm); \( V \) = yarn specific volume, i.e., the reciprocal of yarn density and \( t \) = linear density (tex).

or

\[ d = 4.44 \sqrt{\frac{t}{p}} \times 10^{-3} \]

where: \( d \) = yarn diameter (cm); \( p \) = fibre density (g/cm³) and \( t \) = linear density (tex).

The measurement of yarn diameter has been a problem in textile analysis. This is due to the nature of fiber entanglement during the spinning process, and the dimension variation along the yarn length. Several readings are required to get a representative average of yarn diameter. For the protocol purpose, a method has been employed to measure yarn diameter, quantitatively and non-destructively. It utilizes structural image analysis techniques, in which a digitizing tablet is used to acquire data from projected magnified images of yarns making up the structure of archaeological textiles. In this method, a straight distance between two points across the yarn periphery is traced out, point by point, using the cursor of a digitizer. The data so obtained are transmitted and stored in an associated graphic microcomputer for subsequent evaluations and calculations, including the assessment of statistical significance (5).

A quantitative analysis of the average yarn diameter by itself can be very useful in indicating and comparing the range of yarn sizes employed in the weaving of particular groups of textiles. Accumulation of data in this area would show the spinning limits achieves by different people for certain fibres, which may serve for regional classification and cultural interpretations.

2.2.0. Fabric Construction:
Determination of warp and weft direction, in case of selvedge absence, can be obtained from the specifications of yarn characteristics, mainly those related to construction and twist. The conditions of weaving are such that the yarns employed as warp must possess sufficient tenacity to withstand the imposed strains; whereas any yarn can be employed as
2.2.1. Ends and picks density: The number of ends and picks per cm. is an important parameter directly influencing the weaving process, as well as certain fabric properties, firmness, handle and drape. The loom set-up will also differ in accordance with the warp density. A dense warp requires more shafts to retain a practical distribution of warp ends.

The ratio yarn diameter : thread spacing, can be used to express the relative closeness of fabric construction. It is easy to ascertain the thread spacing (P), by counting the threads per unit length (n), hence, (P) is the reciprocal of (n), i.e., \( P = \frac{1}{n} \). A cover factor may be also used for comparison. It is a number that indicates the extent to which the area of a cloth is covered by one set of threads. For any woven fabric there are two cover factors: a warp and a weft cover factors. In the tex system, cover factor is calculated by multiplying the number of ends or picks/cm. by the square root of the yarn linear density:

\[
K = n \sqrt{t}
\]

where, \( K \) = cover factor; \( n \) = no. of ends or picks/cm. and \( t \) = yarn linear density in tex.

2.2.2. Fabric weight: The number of ends and picks per unit length and their linear density are the main factors in calculating fabric weight. An estimated figure of this weight may indicate special requirements of the weaving device (loom), or suggest the product end-use, or could serve as an interesting criterion for typology.

The simplest method is to express the weight in terms of grams per square meter. By using this method, the weight of the fabric becomes not a function of its width. This standardization is quite relevant due to the fragmentary condition of many early textiles of irregular shape and/or unknown width.

2.3.0. Weave Structure:
In reconstructing early weaving technologies, it is rather important to identify structurally distinct regions within the same specimen. Combinations of more than weave structure and evidence of experimenting and developing new techniques, have been noticed, particularly in the early figured woven fabrics. The existence of transition zones, resulting from changes in the interlacing order, is another interesting phenomenon peculiar to the textiles of late antiquity and early centuries A.D.. These aspects, when recorded and carefully analyzed, could be significant indicators to the development of weaving techniques.
2.3.1. Simple and compound weaves: Weave structures have been primarily divided into two main groups: simple and compound (6). In case of compound weaves, the analysis becomes more complex. Therefore, it might be useful to start with a descriptive categorization, which considers the effect of the structure on fabric appearance. The structure may be distinguished by an apparent face and back, being reversible or formed in layers. This initial categorization will direct the attention of the examiner to look for certain clues associated with different types of compound weaves.

Each set of elements should be isolated, their number in the warp and weft direction identified. The function of each set has to be specified. Then, the interaction among the different sets can be expressed in a numerical order of interlacing; and consequently, the basic weave repeat unit is set up. This unit is the building component of the fabric construction that indicates the smallest area, expressed in number of ends and picks, on which a weave interlacing can be represented.

In most of the studies related to early compound woven fabrics, the weave structure was invariably presented idealistically in a plane view of an interlacing diagram, or in a cross-section either in the warp or weft direction. These presentations can be useful explanatory tools, but if applied in their abstract forms to define the technology of a weave structure, an incomplete or somewhat misleading definitions may result (7). It is recommended that the weave repeat unit should be expressed schematically on point (square) paper. This will allow the developing of a more comprehensive diagram, which includes the weave repeat, the drafts and lifting plans. Without the establishment of this foundation, it would be difficult to grasp the technical principles of a weaving process. Fig. 3, illustrates these inter-relationships, using weft-faced compound twill weave as a case of demonstration.

2.4.0. Design:
The aspects of executing a woven design are considered as an integrated part of the protocol. In addition to the cultural significance of design, it also reflects some important bearings of the technology involved. In designing a textile, use and environment influence a determination of the type of motifs, their general form and dimension. Moreover, practical conditions lead to a definition of the essential constructive elements, and primarily, the choice of material. The arrangement of motifs into a patterns may be based upon the activity or functioning of the designer's mind. However, this arrangement must be in conformity with the materials and implements employed; otherwise the design idea remains in the conceptual realm, and cannot be materialized into a textile form. Designing of woven patterns has to be within the limits both of the texture afforded by the choice of material, and of the implement (loom) capabilities. It may also be realized that the implement - together with the material- actually suggests the pattering mode.
2.4.1. Artistic execution and colour distribution: The aspects of design description related to the sources of motifs, and their artistic execution characteristics (contour and outline) will be recorded for grouping and further inferences and comparisons. The colour distribution is also included, and attention should be paid to the way of introducing colours from the weaving point of view. The dyed yarns may be woven in a consecutive and continuous order, a basic colour may alternate with other colours, or certain colours may be grouped at certain intervals. These characteristics are part of the weaving technique.

2.4.2. The technical pattern repeat unit: Determination of this unit has significant technological implications, and the protocol emphasizes it as a technical attribute. Its analysis can result in indicating the mechanical possibilities of the loom - number of shafts, cords or the equivalent; and the method of arranging the warp ends, their order and manipulation, in a certain loom set-up.

To determine the technical repeat of woven patterns, data on the dimension of the basic pattern unit(s) is required. In some cases, it is worth while to attempt a reconstruction of the repeat when an incomplete repeat survived. The order of repetition considers the aspects of design symmetry. From the aesthetical respect, symmetry in a woven pattern involves an apposition of equal and similar attractive forces on a point or line of equilibrium. The symmetrical adjustment provides the simplest and most obvious manifestation of balance; but in weaving this adjustment is also technically agreeable. Thus, designs on larger scales can be woven much easier, and with lesser mechanization. The analysis of symmetry has been given more attention as being an important factor of weaving design. Recent studies (8), considered and assessed these aspects in a sensible and constructive approach.

Conclusion
The inter-related data resulting from the analysis as prescribed in the protocol, will be tabulated and mapped. The data will be employed to evaluate the technical requirements for reconstructing weaving technologies. Process planning can be developed on these bases. Two plans are required; a drafts plan and a lifting plan. The former determines the number of shafts and the order in which the warp ends are drawn through the heddles before weaving; the latter considers the control and sequence of the shafts' movement to create successive sheds corresponding to each pick in the repeat. A systematic reconstruction of these two plans - in conjunction with the weave structure and pattern repeat - would establish data to assess the minimum and maximum limits of the weaving device capacity. Consequently, possible type of loom(s), and the degree of technological complexity may be explained and better understood.

Few studies related to early textiles have gone beyond the details of technology to place them in a broader cultural
context. The recording of technical data has been done in a scattered fashion, and there is a need to effectively utilize the factual evidence extracted from the inner structure of the extant textiles. The protocol acts as a framework that allows meaningful comparison of data acquired from different investigations. It is a means of supporting stylistic studies, developing hypotheses about craft centres and their habitual features, of explaining and evaluating technological progress and of interpreting intercultural manifestation.

It is hoped that in the future a computer data base and expert systems will be developed to utilize the data provided by following a guided procedure based on the protocol for cultural interpretations. However, logical and objective interpretations will always call for the participation and collaboration of scholars of diverse interests and expertise. Sometimes the realization of this concept of esprit de corps seems far away, but certainly it is not out of reach.

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A PROTOCOL FOR THE RECONSTRUCTION OF WEAVING TECHNOLOGIES: From Experimental Data.

Fig. 1.
Various Helix Angles of Twist:

- 5° very soft twist
- 10° soft twist
- 15° soft medium twist
- 20° medium twist
- 25° hard medium twist
- 25° hard twist
- 30° very hard twist

THE TWIST ANGLE

Fig. 2.
FIG. 3.
THE RELATIONSHIP BETWEEN PATTERN, WEAVE, OPALS AND LIFTING PLANS.
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