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Structuring reconstructions: recognising the advantages of interdisciplinary data in methodical research

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Abstract

A theoretical framework for reconstruction as an integrated scholarly research method across a range of disciplines is long overdue. This paper discusses the usefulness of reconstructed textiles and dress as a template for it. It also argues that there is a need to integrate methods from the arts and humanities with analytical techniques from the natural sciences. The aim is to show how interdisciplinary research not only enriches a reconstruction but provides the mechanism through which cross-disciplinary collaboration takes place. Experimental remaking of historical textiles and dress has tended to be undertaken on an ad hoc basis. For reconstruction to be scientific, it must systematically employ soundly researched evidence from a variety of sources. The triangulation of data—well established in natural and social science—rigorously cross references primary evidence using a range of investigative methods. It produces a firm fix on the material under scrutiny and more credible results than those reliant on only one or two sources. The challenge is that different types of evidence demand specialist approaches, including quantitative and qualitative methods, which are not the traditional tools of dress history. Accurate reconstruction also demands interdisciplinary collaboration: the interrogation of fibres at the molecular level; the collection of observational data at the micro level; and the study of how garments were made and worn at the macro level. This calls for new ways of working with integrated methodologies in pragmatic multidisciplinary teams, which include experts from the humanities, sciences and craft.

Keywords Framework, Reconstruction, Remaking, Recreation, Textile history, Dress history, Interdisciplinary, Craft

Introduction

Reconstruction projects are valuable tools for focusing interdisciplinary research. They offer the opportunity to bring together a variety of different perspectives on a research problem—across theory and practice, the intellectual and the tangible, and from within and outside a range of academic disciplines.

This paper proposes a theoretical framework for the reconstruction of past textiles and dress as a scholarly research method. Textile research has already been acknowledged as a trailblazer in reconstruction-based research. The work of John Peter Wild and Audrey Henshall laid some of the key foundations for experimental archaeology [1, 2]. Despite this long heritage and the many reconstructions made for a variety of purposes, there is no formal protocol suggesting how such projects should be undertaken or reported. If reconstruction is to have credibility as a research method and be applicable beyond dress and textile research, a systematic and scientific approach is necessary. This systematic approach will also ensure that a reconstruction functions as a mechanism through which close collaboration between those working in the humanities, the sciences, and craft may be fostered for new research paradigms to emerge.

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There are four main ways in which dress and textiles are studied: the examination of the object; its cultural context; its production; and/or its practice (consumption and use) [3]. Whichever of these routes is adopted, there are three different categories of primary evidence available: representations, artefacts, and documents [4]. Archaeological and conservation perspectives also acknowledge the potential for investigation of an artefact through molecular analyses with, for example, examination of DNA, dyes, fibres, isotopes, and proteins [5]. There is a well-established tradition of investigating extant material with the latest advances in instrumental analyses to provide direct sources of data such as imaging techniques, fibre identification, condition assessment, radiocarbon dating and protein analysis among textile archaeologists. These tools are also routinely applied to historical material by conservators [6, 7]. There is now an opportunity for dress historians to exploit these techniques and data in similar ways.

A systematic deployment of well-researched evidence from a variety of sources is a prerequisite for a credible research method. The study of these different sources demands different methodologies. These are often the preserve of specialists in different academic spheres who lack a shared objective around which to focus their knowledge and skills. A reconstruction project aims to produce a tangible outcome on which a range of diverse expertise may be strategically focused. A robust reconstruction reflects an historical object such as a garment as the product of a complex interaction of resources, technology, and society [8, 9]. The different types of evidence demand a range of specific knowledge and skills, including the use of quantitative and qualitative methods, which are not the conventional tools of dress history.

Archaeologists have a track record of reconstruction projects or "archaeology by experiment" [1, 10]. Textile archaeologists were not only at the forefront of this movement but have continued it, although the resulting experiments are not always adequately evaluated in scholarly literature [11, 12]. This is partly because there is no theoretical framework against which to report them.

Some good practice has been demonstrated in the investigation of textile tools. The Centre for Textile Research (CTR) in Copenhagen has published rudimentary guidelines for good practice [13]. In contrast, it has been suggested that "researchers, curators and conservators, who have engaged in hands on experimental remaking of historical dress for decades have largely done so on an ad hoc basis" [14]. There is an absence of agreed terminology to describe what is produced and the process by which it is produced in experimental archaeology and experimental history: for example, the terms replication, reconstruction, recreation, and remaking are used without clear definition and in different contexts by different people doing different things [15–17].

This is not surprising since there is almost no literature on how newly made or remade objects are defined as scientific instruments. A spectrum with "historically accurate" at one end and "totally stylistic" at the other has been proposed. The latter is defined as being inspired by historical sources rather than true to them in every detail [18]. A hierarchy with replication at the top, reconstruction in the middle, and recreation at the bottom has also been suggested for textile archaeology projects. Here, replication is the exact duplication of an extant garment, reconstruction uses "justifiable speculation" or "gauze to fill in the gaps", and recreation uses guesswork and imagination [19, 20].

Implied in both the spectrum and the hierarchy identified above is the concept of proximity to relevant primary sources. All newly made or remade dress and textile objects are constructs of assembled information in which empirical data are not the only ingredients. One type of evidence may be privileged over another. The integration of such sources is a highly subjective process. For the purposes of this paper, the word reconstruction is an umbrella term for all newly made textile and dress objects since it contains the helpful notion of a construct comprising a range of elements, including non-empirical information. The purpose of this paper is to recommend principles by which a textile or dress reconstruction is undertaken.

The notion that a replica, indistinguishable from or as close as possible to the original (at the top of the archaeological reconstruction hierarchy) or an historically accurate reproduction (at one end of the historical reconstruction spectrum) has a higher value than a recreation or a totally stylistic reproduction assumes that the purpose of the project is to duplicate the original. Setting a replica as the gold standard of reconstruction presents considerable problems. Most archaeological garments are incomplete or fragmentary. Both archaeological and historical examples often show evidence of wear, remaking or reuse: for example, an early bronze age corded skirt was repaired [21] and a seventeenth century silk satin doublet was widened at the shoulders with additional strips of fabric [22]. It is therefore necessary to choose which part of the object's biography to reconstruct [23].

A more nuanced categorisation of reconstructions has proposed three different models: Model A is as close as possible to the original textile, both in material and production; Model B focuses on the shape of the garment but with the visual details and the processes of production simplified; and Model C concentrates on the form, colour and materials but craftsmanship is less of a priority [24]. The choice of model will be determined by the project's purpose or hypothesis. This emphasises that the point of a reconstruction may not be to achieve precise accuracy in every detail. It may not serve the purpose of an archaeological or historical experiment to make a replica. If the variables under scrutiny are pertinent to the raw materials used or the performance of a constructional detail, it will not be necessary to replicate all the elements to the highest standards.

The model proposed below is intended primarily for the physical reconstruction of historical objects. It may also be useful for digital reconstructions [25–28]. That application is not explored in detail here because it does not offer the primary advantage of a tangible process and outcome, which can be experienced, perceived and tested via the five senses. This important intersection between the practical and the intellectual has been championed as "making and knowing": and hands-on work presented as the only efficient way of acquiring literacy in materials and techniques [29]. In the context of dress, reconstruction "trains visual acuity … to better register the intelligence of the hand that has crafted a garment" [30].

The aim of this paper is to recommend a systematic approach to reconstruction projects to ensure that they produce credible tangible outcomes by bringing together a range of diverse expertise for the purpose of producing new knowledge. The methodology employed to develop the systematic model proposed here was three-fold: (1) A comprehensive literature review of published reconstruction projects was undertaken following a previous study of 30 articles' use of terminology for reconstructions [31]; (2) A prototype model was tested via a reconstruction experiment [32]; and (3) More than 30 years of personal practical experience managing reconstruction projects for different purposes with a range of budgets, deadlines and outcomes was reviewed.

A SMART reconstruction

A useful approach in any project is to set "smart" objectives. These should be: (1) Specific; (2) Measurable; (3) Attainable and assignable; (4) Relevant and realistic; and (5) Timely [33]. By applying this model to textile and dress reconstructions, a set of useful guidelines for good practice for reconstructions in any discipline emerge.

A) Specific purpose—stating a hypothesis

Many reported reconstruction projects produce visually impressive outcomes but have no stated purpose [34]. The purpose of some reconstructions may be entirely functional, such as those used to prepare display mounts for fragile items or to conjecture a missing garment in a suit of clothes for exhibition [35, 36]. However, reconstruction as a scholarly research methodology requires a standard approach which produces comparable datasets and repeatable results [37]. These reconstructions require a clearly stated hypothesis. Three types of such practical experiments have been identified: simulation, production methods and function testing [2]. Simulation refers to reconstructions for display which illustrate research findings so far [38] or for costumed interpreters to wear at heritage sites [39]. Production experiments investigate the role of textile tools or tacit knowledge in the process of production [40, 41], or calibrate measurements such as how long it takes to spin, weave, knit or full materials [32, 42, 43]. Function testing includes how garments affect movement [44, 45], who wore them [46, 47], how they were worn [15] and how that wear affected the fabric [48]. It also extends to testing textiles other than garments such as reconstructed Viking ship sails [49]. Experimental archaeology projects have also investigated the sensory experience of clothing, tested a garment's effectiveness, and identified new significant parameters for further research [50].

In order to have a hypothesis to test, researchers need theory [51]. Dress and textile specialists have been identified as slow to embrace the need for theory even though it has been defined as "a set of statements that advance knowledge by describing, explaining, or predicting the relationship between two or more concepts" [52], which many textile and dress historians propose on a regular basis [53]. Testing a theory requires the identification of variables. It determines which of them will be investigated, and which will be controlled. This also informs the design of the experiment, suggests the resources required, how relevant data will be collected, and how its outcomes are evaluated.

B) Measurable outcomes—designing data collection and evaluation

Identifying the purpose of a reconstruction project suggests the appropriate method of data collection. There are two categories of measurable outcomes: the data to be collected and analysed; and the evaluation of the project's success. Experimental archaeology projects collect quantitative data drawn from specific measurements and/or qualitative data using systematic observations (such as evidence perceived through the body) which is recorded using words or numbers in a logbook, diary or spreadsheet [54]. Published historical reconstruction projects which do this are few and far between, although some have very specific hypotheses: for example, whether a specific person could have worn a garment associated with them [46].

A study of Early Modern knitted caps focused on the fulling process with the fleece identified as a crucial

Fig. 1 Reconstructed miniature versions of the flat, circular linings inside the original early modern caps served the purpose of testing the fulling time for five different sheep's fleece (source: Jane Malcolm-Davies)

variable in producing the characteristic plush nap [32]. Miniature versions of the flat, circular linings inside the original caps were less complex to reconstruct and test than the caps themselves (Fig. 1). In this case, data collection concentrated on the time it took for the fulling process to produce a change in the knitted fabric, the depth of the nap produced, and the extent to which it obscured the loops in the knitting. Some qualitative assessments were undertaken too, such as how silky the different naps looked and felt in relation to each other. The reconstruction experiment served the hypothesis by indicating which of the fleece performed best under repeatable conditions.

In addition to the data drawn from a reconstruction, it is recommended that all "products" be submitted to an objective analysis by external experts, according to the CTR guidelines [13]. Evaluation in this context is similar to that undertaken by the peer reviewers of an academic article. This task is becoming increasingly formalised with the use of specific criteria in structured or semi-structured formats [55]. Peer reviewing is usually undertaken without a fee. If travel or other expenses are necessary for evaluators to examine a reconstruction and/or extant objects which have informed it, these can be apportioned appropriately in a research budget.

The evaluators' role is to assess how well the reconstruction serves the hypothesis of the research not to judge how "authentic" it is. Authenticity is a word much cited in the discussion of reconstructions. It is often used to suggest how accurate a reconstruction is. In current use, it has several shared, and often muddled, meanings [56]. Only an original item has authenticity [57]. It is therefore not suitable for use as a scale by which reconstructions may be measured [58].

A more helpful concept is that of accuracy [59]. This has been adopted by conservators working with oil paintings to describe the use of materials appropriate to their time of creation with the aim of producing reconstructions at the material level as well as in surface appearance. The "Historically Accurate Reconstruction Techniques (HART)" model incorporates the international standard which defines the scientific concept of accuracy (Table 1): ISO 5725 [9]. The accuracy of oil paintings reconstructed using HART were evaluated in part by how well they performed under various standard analyses such as scanning electron microscopy (SEM). A similar test was used in the evaluation of dyed tablet-woven wool bands based on those found at Hallstatt in Austria. The modern parameter of colour fastness was measured on the relevant standard scale from 1 to 8, with the target being 3 to 6. One of the reconstructions scored 3 and the others between 5 and 6, although these were lower than the scores for colour fastness of the original bands [8].

A project which employed an exemplary third-party assessment of its outcomes was the reconstruction of

Table 1 Carlyle's model of accuracy ([59], fig. 2) based on ISO 5725–1 applied to the reconstruction of a seventeenth century knitted silk waistcoat showing how proximity to "trueness" is affected by the materials (X), how they are processed (Y), and levels of craft expertise employed (Z)

Accuracy/trueness	- (relatively less accurate)	± (between relatively less and relatively more accurate)	+ (relatively more accurate)
Materials (X)	Artificial	Semi/part natural	Natural
	100% wool (or another non-silk fibre)	Silk/wool blend (or another non-silk fibre blend)	100% silk
	Spun and plied	Spun	Reeled
	Commercially dyed	Artificially hand dyed	Organically dyed
Processing (Y)	Industrial	Semi-industrial	Handmade
	Knitting machine	Handknitted	Handknitted
	Hooks	Circular needle	Multiple double-pointed needles
	Flat knitting, sewn to shape	Round knitting	Round knitting
Labour (Z)	Beginner	Learner	Expert
	Amateur, inexperienced, self-taught knitter	Semi-professional, limited experience, part-qualified knitter	Professional, experienced, qualified knitter

an 1880s gown. Three different ways of drafting patterns from the original were evaluated to see which created the best reproduction. A panel of 12 people independently assessed the reconstructions against the original garment. They used a five-point rating scale, a separate list of features to compare, and undertook a ranking exercise. These evaluation instruments together produced a mathematical score for each of the pattern drafting methods under scrutiny [60]. The involvement of a panel of experts and the development of an evaluation instrument for them to use offers a practical way of gathering comparable feedback on a reconstruction.

In contrast, there is a trend for reconstructors to be their own evaluators. It has been argued that the arts-based approach of "reflective rationality … usually involving hands-on experimentation and observation … is vital to understanding the skills and design knowledge of early modern artisans" [61]. A lack of expertise has been acknowledged as a strength of reconstruction experiments: "Exposure to the experiential knowledge of materials and techniques makes people "aware of what they do *not* know" [62].

Reflective rationality may be both a method of data collection and evaluation. But there is distinction between what may be learnt through the reenactment of a production process by an inexperienced researcher-gone-crafts–person (see below) and the reconstruction of an object by an expert practitioner. Reflective rationality is a useful approach even for a researcher who lacks "the embodied expertise of an early modern craftsperson" because "reconstruction allows them to gain a much clearer sense of what was at stake in acquiring and exercising material literacy, at least to the point of being able to better read historical objects, and to appreciate what kind of gestural knowledge their creators would have had to possess" [63]. If the reconstructors are not expert practitioners, what they experience is the process of becoming aware of their own limitations: "Primarily, this experiment taught me to think more like an artisan and less like a scholar, often the result of learning from mistakes" [61]. If the purpose of a reconstruction is to learn something about the materials' properties, the construction methods or how the garment functions in wear, then it is better done by an experienced practitioner who will avoid a beginner's mistakes and ensure a more legitimate set of results. Likewise, when data on a reconstruction experiment is generated by the reflections of a researcher who is not an expert, it is important to limit conclusions to those related to the experience of the non-expert and avoid extrapolating the outcomes to assumptions about how such objects were made or behaved in the past.

C) Attainable and assignable tasks—deciding who does what with what

The third component of a scholarly approach to reconstruction is the allocation of attainable tasks to competent specialists. The CTR's guidelines recommend "it is essential that tests are performed by several skilled craftspeople, otherwise it will not be possible to evaluate if the end product is affected by the tool or by the craftsperson … and to secure a more objective assessment of the results" [13].

Arguably, the loss of craft skills presents the greatest barrier to competent reconstructions for scholarly purposes. Craft is a living tradition—as recognised by UNESCO, which called for the preservation of intangible cultural heritage as long ago as 2003 [64]. Despite this, integrating craft expertise into a scientific reconstruction is still a challenge because it does not have a widespread academic presence. Very few universities have an academic discipline in craft, and textile crafts are particularly poorly served. There are notable exceptions: academics at the Department of Estonian and Comparative Folklore, at the University of Tartu, Estonia, have taken a scholarly approach to the craft of knitting [65]; and the textile studies team in the art history department at the University of Uppsala includes academics with specific training, skills and qualifications in tailoring, weaving and lacemaking.

Collaborations between university researchers and expert craftspeople have been reported [66] and there are examples of trained practitioners who apply their skills in academic work [67, 68]. But often the tacit knowledge and valuable insights of expert craftspeople go unharnessed and/or unrecorded. An appreciation of craft practices bridges the divide between the study of the materials (fibres, processing and construction) and the study of meaning (culture and context). For these reasons, positioning craft at the centre of a reconstruction is an important part of the research methodology (Fig. 2). It has been argued that this type of embodied skill or tacit, unarticulated, unexpressed, silent knowledge, which is not formalised or written down can be problematic in a scientific context: "It is personal, subjective and does not easily submit to a standard scientific testing and rigour" [69]. But it is possible to learn crafts through recognised qualifications, apprenticeships and training programmes. Craft expertise is also recognised by years of experience as a practitioner and through recommendations from

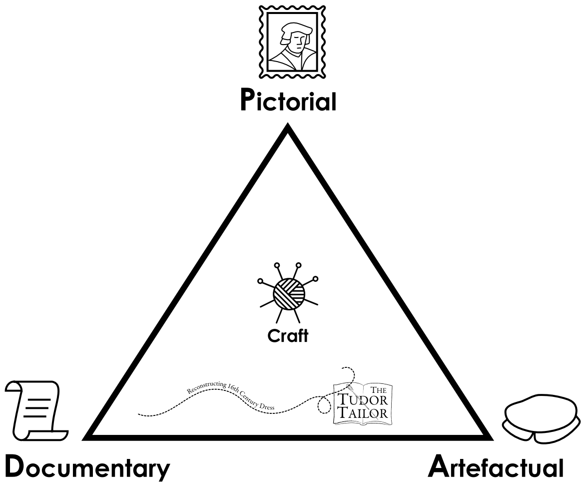

Fig. 2 A model of good practice for auditing primary and secondary sources of evidence and today's labour resources for reconstructions (source: The Tudor Tailor, image: Jane Malcolm-Davies & Jodie Cox)

other professional craftspeople. A craftsperson who makes their main living via their craft and provides a professional service is likely to be more expert than a self-taught hobbyist, although for craft practices for which there are no surviving or uncertain training methods, a long-served amateur apprenticeship may be the only source of expertise.

Reconstructing dress and textiles in this way takes time, effort, energy, specialist expertise, physical skill, and significant financial resources. Citizen science is a model of scientific research which has the potential to recruit a large number of people with a range of experience, who, under the direction or with the assistance of experts, can contribute their volunteer labour to an otherwise expensive undertaking. It began with the pioneering use of idle computers for identifying Mersenne prime numbers in 1996 for which 1.25 million participants were recruited to generate what has more recently been dubbed crowd-sourced knowledge [70]. Citizen science also offers other advantages. Some of the volunteers may be experts who wish to participate in academic research and others may be fast workers with time on their hands. Craft fits the definition of serious leisure for many who participate in it, and it is known to foster wellbeing and offer other therapeutic effects [71]. However, managing volunteers to ensure they provide valid data and gain some personal benefit from participating is an extra responsibility which may not sit well with all reconstruction projects' aims, objectives or resources.

Whether the craftspeople are paid experts, serious leisure seekers or somewhere between the two, it has been suggested that "crafts in experiments may need to be evaluated with greater care and the uncertainties they contain must be recognised" [69]. This is particularly challenging in the case of the "researcher-gone-craftsperson" for whom the possible conflicts of interest this combination presents have been noted [72].

D) Relevant evidence and realistic interpretation of it

There is a well-established tradition of triangulation in the natural and social sciences, by which a range of evidence is gathered via different investigative methods and is rigorously cross referenced [73]. This provides a firm fix on the material under scrutiny and produces more credible results than those which rely on only one or two sources and only one or two methods of investigation [74].

A comprehensive audit of the available evidence for a reconstruction will suggest the appropriate variables to be tested, and note when there is a complete lack of relevant material. Variables are ascertained with thorough research into what is known from the three main sources: Pictorial evidence, Artefactual evidence and Documentary evidence. Surveying these sources for a reconstruction produces a "PAD", a firm foundation on which it stands, according to The Tudor Tailor's model (Fig. 2). However, in the same way that craftwork requires specialist skills, so too does the study of sources. A systematic approach to all the available evidence requires a range of methodologies.

Pictorial evidence is usually studied via traditional art historical methods which sometimes take an anecdotal approach to it: this evidence includes crucial information at the macro level such as how a garment was worn and in what context [75]. There are also relevant lessons to be drawn from the role of connoisseurship in art history, including the detailed recording of an object, comparing and contrasting similar examples, and exploration of its material for clues as to how it was crafted [76, 77]. These suggest the credibility of the evidence for textiles and dress represented (such as the accuracy with which texture is represented). Visual evidence can also be explored in very systematic ways [78, 79]. There are methodologies drawn from the social sciences available for interrogating pictorial sources as quantitative evidence. These use databases with keywords which identify garments and other features of dress [80, 81], although there is much work to be done in developing terminology which has universal application in this context.

Artefactual evidence comes from the study of the object itself for which general guidance has been provided [82]. This is not a methodology which has been well documented in textile and dress research, although some literature which suggests how textile structures may be described in detail has been put to good use in archaeology [83–85]. Some practitioners have published exemplary reports on extant examples but there are no step-by-step guides to this kind of recording [86]. This may go some way to explaining why there are so few comprehensive and accessible reports on historical garments available. Curators have published "how to" guides [87, 88], others have hinted at how detailed records might be compiled [89, 90], and conservators have developed appropriate ways to take precise measurements from garments [91].

A textile or dress object provides primary evidence at the macro level such as its dimensions. These include the details seen with the naked eye or a basic magnifying glass which can be quantified or measured. There are also the details at the micro level such as the fibre diameter. The examination and description of an artefact in these terms is relatively straightforward, especially when conventional protocols are followed such as the expression of warp followed by weft as threads per unit (centimetre, ten centimetres or inch) for woven fabrics and gauge per unit for knitted fabric (see *Knitting in Early Modern Europe* for specific measurements of knitted garments [92]). A number of conventions are in use to describe textile objects such as CIETA's for woven fabrics (2022), Walton and Eastwood's guide (1988), proposals for refinement such as Splitstoser's (2012), and protocols specific to non-woven textiles [85, 93–96]. Spin angle is measured in degrees from the vertical with the direction indicated as "s" or "z" (lower case letters) and the ply and its twist as "S" of "Z" (as uppercase letters), with the thread/yarn diameter in millimetres. More difficult is the definition and description of colour without recourse to systems such as the CIELAB and Munsell, which are not routinely used [97]. Colorimetric methods now allow for non-invasive and precise colour identification in historical artefacts in general and in textiles such as tapestries in particular [98, 99].

The non-specialist has access to the micro level of an original object via the use of user-friendly and affordable USB microscopes (such as Dino-Lites) which make higher magnification observations possible without specialist training. These were previously only possible with fixed, more expensive, and less accessible stereo microscopes, although it remains to be seen whether their use provides similarly accurate results. The micro level of observation includes fibre identification to suggest the animal or plant from which it came and fibre diameter measurements to assess the quality of the material (conventionally based on 100 fibres) [100, 101].

The micro level of study using powerful optical equipment such as scanning electron microscopes reveals more about the material under investigation than is available at the macro level. These observational techniques usually require specialists such as conservation scientists who are trained to use them [102]. This puts them one step beyond most textile and dress historians' reach whereas archaeological specialists are more likely to have had relevant training because of the emphasis on scientific approaches to excavated material.

Beyond that, artefacts may be studied at the molecular level using techniques such as x-raying, micro CT-scanning, radiocarbon dating, proteomics, and isotope analysis (see Table 2) [103]. However, the integration of this type of work into textile and dress reconstruction has been slow to evolve. Understanding the origin of materials (for example, the species of plant/animal and geographical provenance), their morphology (for example, shape, form), their treatment, colours and fixatives (for example, with dyes, mordants, glues) and how they were processed (for example, reeled, spun, plied) helps a researcher decide where appropriate compromises are to be made for the hypothesis under consideration [8, 104].

Documentary evidence (including secondary source material such as work by earlier researchers or transcripts of interviews in oral histories) can be interrogated in many ways including qualitative and quantitative study. There are many helpful guides to using archival sources [105–110]. Economic historians of dress have demonstrated the value of large statistical studies of archives [111]. Databases now facilitate quantitative analysis of documentary evidence and there are guides to their construction available [112–114].

A thorough audit of these three sources of primary evidence will inform the crucial decisions and compromises to be made regarding the materials to be used, the constructional details, finishing techniques, and embellishments (Fig. 3). A further audit of the resources available to match or approximate these may demonstrate that compromises must be made [115]. These should be thoroughly documented [116]. Any "justifiable speculation" will only be legitimised with a clear rationale based on a triangulation of sources and the availability of modern resources: "Patient exploration of all the alternatives will serve science better here than mere enthusiasm to produce something tangible" [19].

E) Timeplan—scheduling appropriate deadlines

The project schedule should include adequate time for the purpose to be identified, the primary evidence audited, interrogated and triangulated with any

Table 2 The integration of scientific analysis with reconstruction as a scholarly research method

Method	Identifies	Aids decision making for resources
Scanning electron microscopy (SEM)	Fibre	Materials
Dye and mordant analysis	Original colour/s, dyestuffs	Materials
Fourier transform infrared spectroscopy (FTIR)	Chemical compounds	Materials
Surface-enhanced Raman spectroscopy (SERS)	Natural dyes	Materials
Molecular fluorescence	Natural dye recipes, dates, locations	Materials
X-ray fluorescence spectrometry (EDXRF)	Chemical elements	Materials
Radiocarbon dating	Age	Materials
Isotopic tracing	Geographical provenance	Materials
Proteomics	Proteins, animal/plant species, age of animal/plant	Materials
DNA analysis	Fibre, plant/animal species	Materials
Multispectral imaging	Dyes	Production methods
Photogrammetry	Surface texture mapping	Production methods
Micro-CT scanning	Structural mapping	Production methods
X-raying	Structural mapping – hidden folds or layers	Materials and production methods

Identification of the above provides vital evidence for materials to be sourced and used in reconstructions. Subsequent decisions on appropriate resources are based on the environmental resources at the point and date of origin, methods of production available in that locality at that time, and known trade routes

speculations appropriately recorded, resources identified (including appropriate labour recruited and briefed) with compromises documented, the reconstruction completed, relevant data collected from it, and the evaluation undertaken. All these stages of the project should be adequately recorded for the reconstruction to be regarded as robust and scholarly.

Time is likely to be required for preparatory work to test materials and/or tools for a more complex phase of experimentation. These results will form part of an iterative process of investigation. It is also recommended that the time plan allows for repeated experiments because the first reconstruction may reveal fundamental flaws in the materials or method of work, which are be corrected in subsequent reconstructions. A process of trial, error, review, rethink, repeat is likely to produce the most useful results [41, 117]. One exemplary study produced six garments for comparative evaluation to identify the most satisfactory outcome [67].

Case studies

Two case studies serve to illustrate the SMART model in practice. The first project was devised in line with the model and the second project was a test case mapped on to the model retrospectively. These two overviews are not models of how a reconstruction project should be reported. They are checklists demonstrating how the SMART model is applied for project planning and execution. The first case study demonstrates the application of the SMART model to a reconstruction project focusing on a seventeenth century knitted silk garment at the Museum of London (inventory number A27050) said to have belonged to King Charles I. The reconstruction project aimed at investigating the materials and techniques used for knitting a man's waistcoat in the early modern era [118].

Case study 1: A seventeenth century knitted silk waistcoat

A) Specific purpose

The first hypothesis was that a modern silk thread with a diameter of about 1 mm knitted in the gauge (the number of wales and courses per 10 cm) of the original would produce a fabric which replicated the look and drape of the original. The second hypothesis was that a reconstruction based on a published pattern of the decorative motifs would pinpoint the suspected errors in it [119].

B) Measurable outcomes (data and evaluation)

The data to be collected from the reconstruction were overall measurements (length, circumference, depth and width of motifs), number and placement of the motifs, and the gauge. Evaluation of the success of the reconstruction was assessed by a panel of four textile/dress experts (a curator of dress history, an archaeologist/crafts-person, and two textile historians/craftspeople) who completed a three-part questionnaire asking for comparisons between the original and the reconstruction. They were asked to comment on specific characteristics and give a score to their overall impression, materials used, construction techniques and provide recommendations for improvement.

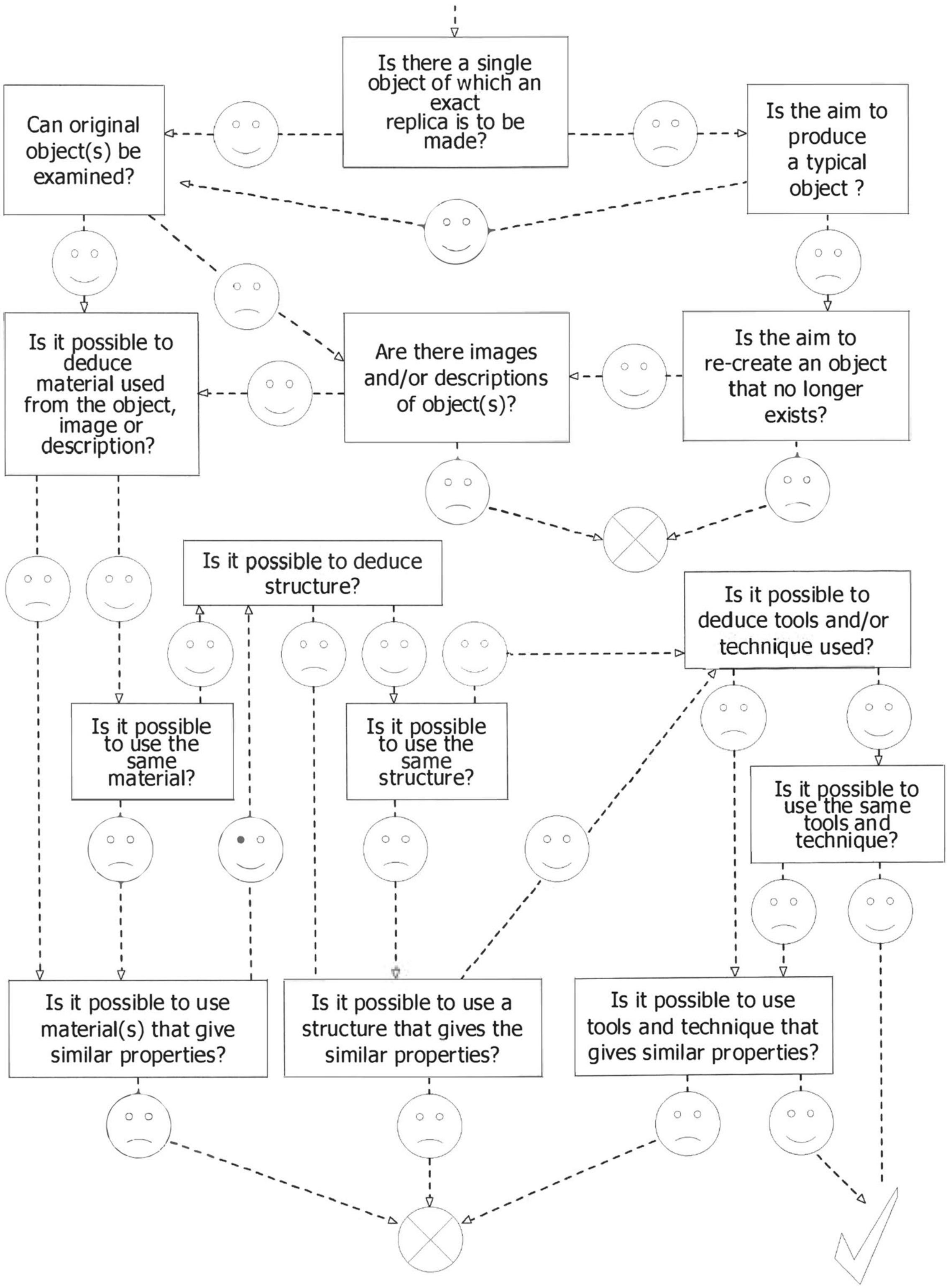

Fig. 3 Decisions taken in planning a replica artefact as opposed to a reconstruction (source: Gilbert 2005, Fig. 14, p. 19)

C) Attainable tasks assigned to appropriate specialists and achieved with appropriate resources

3a Specialists and tasks

A team of specialists was recruited including a professional historical costumier with extensive handknitting experience, a doctoral student with a special interest in the reconstruction of historic dress and professional experience in handknitting, a semi-professional spinner with experience of working with silk, and a masters student with experience of reconstructing historic knitwear using a knitting machine. Each had the opportunity to view the original garment, take notes and photographs, and share background information on the garment such as relevant literature. One volunteer knitter also joined the team (Table 1).

3b Resources

The team worked with silks which were available to buy commercially although none replicated the original silk precisely. The spinner also experimented with a range of processed and raw silks to see whether they could be spun or reeled to a suitable dimension. The test swatches they produced were compared and the nearest commercial silk to the original selected. The knitted swatches also provided evidence for an estimate of the time it would take an experienced knitter to knit a complete waistcoat. However, there were several critical construction issues to resolve before investing the time to reconstruct the whole garment. A previous project had recruited volunteers to knit very fine gauge silk stockings for whom one stocking seemed a manageable task [120]. Knitting a sleeve was a comparable task and well within the competence and time available for the historical costumier. A sleeve also required far less silk than a full waistcoat. It was possible to buy off-the-shelf embroidery silk with very little spin which was close to the original but too wide in diameter. Eight double-pointed 1.2 mm needles were necessary to achieve the gauge required for the fabric and the circumference of the sleeve at its widest.

The commercial silk selected for the reconstruction required a few compromises. It was only available in a golden colour (an undyed version would have been preferable because the results of dye analysis will be taken into consideration later in the project). The thread diameter was thicker than the original which made the knitted loops bigger. This required an adjustment in the number of pattern repeats possible in a sleeve of the same dimensions as the original.

D) Relevant primary evidence—audit, triangulation and interpretation

A review of relevant pictorial, artefactual and documentary primary sources demonstrated that extant waistcoats present the greatest quantity and quality of evidence. There are no known depictions of men wearing knitted waistcoats although two paintings in Scandinavian churches are thought to show women wearing them under other garments [121]. There are 22 damask or purl-patterned knitted waistcoats in museum collections similar to the one under scrutiny here [122]. There are references to knitted waistcoats in archives, including wills bequeathing them. Charles I was supplied with knitted waistcoats by his haberdashers [123]. However, these sources do not provide much detail about the silk from which they were knitted or how they were made.

Magnified Dino-Lite microscope images of the silk (from × 15 to × 55) provided the opportunity to examine the structure of the thread and look for evidence of dye. This established the lack of spin and ply. These images also confirmed the gauge and direction of the knitting and details such as the method of shaping (increasing). It was not possible to establish with certainty how the false seam/jog was constructed because access to the inside of the garment was restricted. Images taken at × 435 magnification suggested a few fibres were saturated with blue dye although it was possible that these were contamination rather than original material. Microfadometry testing (MFT) was undertaken to consider appropriate display, lighting and storage arrangements in the future. This suggested that the colour of the waistcoat has already undergone substantial fading but that there was some evidence of an indigo dye. Further dye analysis was undertaken using x-ray fluorescence (to identify inorganic material such as metal mordants) and fibre optic reflectance spectroscopy (to identify organic colourants). Raman spectroscopy and surface-enhanced Raman spectroscopy (SERS) also suggested an indigo dye was used at some time in the waistcoat's history. High performance liquid chromatography (HPLC–DAD-MS), a destructive test, will be undertaken before the next phase of reconstruction project to identify the organic colourants more precisely.

E) Timeplan

The schedule for the waistcoat research project was imposed by the requirement to provide reports to external funders on specific dates and constraints on the period within which the budget was to be spent. The project was undertaken within 18 months, although this did not include all the time required to draft reports and publications. Some necessary restrictions on access to the waistcoat were imposed by conservation before it went on display for seven months. The reconstruction phase of the project began with the team viewing the garment, followed by a six-month search for appropriate silk thread and experimentation with samples. Once decisions were made on the materials, the sleeve was knitted in a month. A review meeting for the reconstruction team was held one month after that and the evaluation day three months later (once the waistcoat was out of the exhibition).

The data collected during the project provided clear guidance on the specification for reeled silk thinner than the commercial embroidery silk available for the first reconstruction. The data also gave a reliable indication of how many hours it was likely to take a professional knitter to complete a whole waistcoat. One sleeve represents an estimated 17% (one sixth) of the whole garment, which suggests a waistcoat will take 600 hours of knitting. The evaluation of the knitted sleeve identified amendments to specific characteristics which will bring it closer to the original: a change in knitting technique to avoid twisted loops with one leg longer than the other; the jog or false seam requires one additional wale; and a blank area (with no motifs) on either side of it.

The second case study demonstrates the application of the SMART model to a reconstruction project focusing on a material used in dress (as a textile support, as a stiffening, and for marking out design templates). It is also used as a medium for writing more usually known as vellum. The reconstruction project described here aimed at investigating the feasibility of handcrafting parchment which would be suitable for creating a copy of an original document dating from 1814 [124].

Case study 2: An early nineteenth century parchment treaty

A) Specific purpose

The hypotheses were that detailed methods and tools for making parchment described in the 12th and 18th centuries would produce a more acceptable medium for writing than modern commercial production processes. Parchment prepared using today's industrial chemical treatments and machine sanding processes does not provide a surface suitable for writing. The reconstruction project proposed using only materials and specially made tools described in historical sources.

B) Measurable outcomes (data and evaluation)

The measurable outcomes for the project were that the handcrafted parchment would provide a sufficiently thin (0.2 microns) smooth surface on both the hair and flesh sides suitable for writing with a goose quill and ink. Evaluation of the success of the project was assessed by manuscript conservators familiar with early 19th century parchment who were able to compare tool marks observable on the original documents with those on the reconstruction. The parchment was also evaluated by a team commissioned to produce other elements of a reconstruction of the Treaty of Kiel signed between Denmark-Norway, Sweden and Great Britain in 1814. The final evaluation was the acceptability of the reproduction for display by the Norwegian parliament, which had commissioned the work [124].

C) Attainable tasks assigned to appropriate specialists and achieved with appropriate resources

3a Specialists and tasks

The reconstruction was prepared by a parchment conservator with fifteen years' experience of experimental parchment making, in collaboration with an experienced professional calligrapher [125].

3b Resources

The materials used were salted skins from six-month-old calves. The stillborn animals used in the past are no longer commercially available. The skins were washed, rinsed and soaked in slaked lime for two weeks after which they were dehaired and partially defleshed on both sides with the blunt edge of a curved knife (on the hair side) and a sharp blade (on the flesh side) against a wooden beam. They were further "scudded" to remove the lime and thin them down – in some places from a thickness of 1cm. The skins were then stretched on herses (wooden frames) for shaving with the sharp edge of a semi-circular "lunellum" knife and pumicing with chalk. This work completely removed the hard, gelatinous material on the hair side to produce a surface identical to the flesh side [124].

D) Relevant primary evidence—audit, triangulation and interpretation

A review of relevant pictorial, artefactual and documentary primary sources revealed many medieval images of parchment makers with their equipment and tools [124]; for example, St Jerome in the *Hamburg Bible* of 1255 [126]. Close examination of the original treaty showed there were no holes in the folia supporting the main text and that the hair sides absorbed the ink just as efficiently as the flesh sides (without any penetration to the other side [124, 127].

A white deposit is visible in the wrinkles at the edges of the parchment folia. This has been identified chemically as calcium hydroxide. There are even indications of a dried lime crust where parts of the skin floated above the surface of the liquid. This is evidence of slaked lime providing the alkaline bath to remove the animal's hair. There are also marks left by different tools, especially knives, which were used for shaving, scraping and smoothing the surface and to reduce the skin's thickness. The presence or absence of these is observable on both sides of the parchment providing evidence of which processes were necessary for which types of skins. Other clues to the preparation of the parchment are provided by unfinished peeling, striation marks from shaving the hair side of skin, and tension lines showing the direction in which the skin was stretched [128].

A detailed account of the preindustrial processing of parchment provided further step-by-step guidance as text and in engravings [128]. A further documentary source which provides detailed instructions for making parchment was also identified. These were included in a German medieval compendium of crafts written in Latin between 1110 and 1140. It includes descriptions of the various activities for transforming animal skin into parchment. Among other detailes, it explains that the lime bath will take twice as long in winter as in summer to be effective [129].

E) Timeplan

The skins are most efficiently processed in the summer when the warmer temperatures ensure that they need only be soaked in slaked lime for two weeks. This is also when the weather is better for working out of doors and the skins will dry more quickly than in the winter. The first two days of work required the skins to be repeatedly rinsed and scraped while wet. This was followed by at least another two days for the skins to dry naturally and stretch (depending on the weather and thickness of the skin), and a further two days for dry working [130]**.** Most of the reconstructions made to test the hypotheses that historical lime-based methods and tools could successfully produce appropriate parchment for writing were made as part of a larger batch after Easter to take advantage of the warmer weather [131].

The parchment maker and the calligrapher worked together to ensure that the reconstruction's surface had the same quality as the original Treaty of Kiel. Both the quality of the texture and its thickness were similar to delicate suede and, as a result, both hair and flesh sides took the ink well. They lacked the shine which causes ink to flow uncontrollably. The lack of hair helped the calligrapher achieve speed and precision in copying the original text [124, 125]. The reconstruction was sufficiently close to the original for it to be displayed at the Storting (parliament) archives in Oslo, where it may be viewed today.

These two case studies go some way to demonstrating the application of the SMART reconstruction model and showing that "the skill of makers must be taken seriously as a form of knowledge and that collaborations between makers and scholars are one way to break down the extremely pervasive and long-enduring partitions between mind and hand and between making and knowing" [132].

Conclusion

Scientific reconstruction is the mechanism by which a variety of methodologies can come together to generate new knowledge by cross referencing a range of different primary evidence. There is a need for a model of good practice for experimental reconstructions in both archaeological and historical research which includes the triangulation of data, the control of variables, and the evaluation of outcomes. Recognising the role of interdisciplinary team working in systematic textile and dress research is long overdue, although it is not unusual in this omission [15]. The statement of a specific hypothesis directs the collection of useful data and makes it possible for a reconstruction to be evaluated according to the project's objectives and not against a vague and troubled notion of authenticity. It is recommended that researchers structure reconstructions in a scholarly fashion by identifying:

A) A specific purpose stated as a hypothesis with variables to be tested;
B) Measurable outcomes with appropriate data collection and evaluation;
C) Attainable tasks which are assigned to appropriate specialists and achieved with appropriate resources;
D) Relevant primary evidence through an audit, triangulation and interpretation of it; and

E) A timeplan which schedules the processes and products of the project with appropriate deadlines.

This model of good practice will encourage smart ways of working with integrated methodologies in pragmatic multidisciplinary teams [133], which include experts from the humanities, the sciences, and craft. Further strategies for closer collaboration between researchers building reconstructions and those investigating the original objects is encouraged to ensure that the eloquent primary evidence from surviving artefacts gives voice to the interplay of the raw materials, the processing and the production of textiles (and other objects) in the past.

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