Review article

Advances in CAD/CAM application in weaving industry

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1 Introduction

Weaving is one of the oldest crafts known to man. Fragments of woven cloth have been dated to the Neolithic/Eneolothic period [1]. The woven fabric has been regarded as possessing mystical qualities: woven rags are offered as part of the prayers in some Buddhist shrines, form the requisite set of ceremonial accoutrements for many different religions' prayer settings, and as observed by Kramrisch [1a] "in the Rig Veda and the Upanishads, the universe is envisioned as a fabric woven by the gods. The cosmos, the ordered universe, is one continuous fabric; the uncut fabric is a symbol of totality and integrity" [1a, pp. 67–68]. Knowledge and mastery of the skill has long been a matter of intellectual pride – as illustrated by the Greek myth of the weaving competition between the goddess Athena and the human Arachnida. Arachnida won the competition but her demonstration of pride in winning was punished by Athena who turned Arachnida into a spider and cursed her to forever spin and weave. To understand and be knowledgeable about woven design is a matter of mastering weaving techniques and mathematics and the competitive environment within which the textiles industry operates requires computer-aided design and manufacture (CAD/CAM) skills to develop new products and new textiles applications.

This article introduces the reader to some of the key issues regarding the use of CAD/CAM within woven textile design. The chapter will begin with an overview of the scope and standing of the textiles industry within the global trading environment and the role that CAD/CAM plays. The chapter then discusses key management issues when using CAD/CAM within the woven design process such as: cost, expertise and skills training, impact on the supply chain, and development of new products and new market areas. The chapter will conclude by discussing some of the current research being undertaken with CAD/CAM applications for woven textiles with a view towards future trends and sources of useful information for readers wishing to explore the issues raised in greater depth.

2 The textiles industry and innovation

2.1 Scope and size of the textile industry

The textiles sector is wide and diverse with applications as diverse as clothing, geology, architecture, auto industries, civil engineering, medicine, aerospace, etc. [1b]. According to the latest available COMTRADE figures, textiles (not including apparel) are one of the top 25 globally traded goods; it is 17th of 25 goods valued at about $0.35 trillion of the total goods traded globally valued at $25 trillion [2]. The textiles industry has traditionally been regarded as consisting of three main production areas: fibres (natural or synthetic), fabrics, and the finished product (consumer goods, e.g., clothing, domestic interiors). Production of fabric (the first two main production areas of the textiles industry) is capital intensive, requiring technology and automation to produce requisite volumes of fabric. Although more labour intensive, the third production area, which is the consumer facing end of the chain (import, distribution, and retail) has become increasingly competitive and significant in the industry's value chain [2a, 2b] and new applications of textiles have led to expanding market potentials for technical textiles. Indeed, it has been noted that there are four specific areas where value could be incorporated or improved through product or process: flexibility, quality, environmental performance, and innovation [3].

New technology, research, and development activities are regarded as essential factors to compete within the capital-intensive countries (such as those within the OECD) as it helps to develop products that are differentiated from competing companies and are able to be traded within the saturated market conditions. CAD/CAM applications play significant roles in developing differentiated products and reacting to the changing nature of the supply chain. An area of innovation in textiles where CAD/CAM is essential is technical textiles and three-dimensional (3D) weaving, because of its complex weave structures and interdisciplinary nature of working.

2.2 3D weave and technical textiles

Technical textiles may be knitted or woven fabric structures [4]. Defining technical textiles has proven difficult as it was originally coined as a term in the 1980s to follow on from the term 'industrial' textiles (which is still used in the United States), as it was regarded as too narrow in scope of applications (https://technitex.org/). The term in its original use became too narrow because it was initially regarded as "textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics" but the rising use of technical textiles within sportswear apparel and the increasing use of design to attract sales has rendered this approach somewhat narrow (Byrne, in Ref. [5]). Byrne [6] provides some common features of technical textile products: they are the results of understanding and know how about combinations of the techniques of manipulating fibres, fabrics, and finishing and how they perform in different combinations and environments.

Woven technical textiles tend be developed using 3D weave structures. Woven fabrics may be single layer or multiple layers and the weave structure may be as simple as plain weaves through to complex weave structures, depending on the final product requirements. Multilayer woven fabrics are also known as 3D weaves, as they have several layers of warp and weft yarns woven together in an almost infinite number of possible ways, but broadly categorized as orthogonal, through-thickness angle interlock and angle interlock (also known as layer to layer). Braided fabrics (created by interweaving three or more yarns in a diagonally overlapping pattern) are also commonly used to develop technical textiles. Two types of braided fabrics are widely available, biaxial (two sets of aligned yarns) and triaxial (three sets of aligned yarns).

As with woven fabrics, multilayered (3D) braided fabrics are also manufactured. Three-dimensional weaving may result from specific loom technologies such as 3Tex and Biteam or through a conventional weaving loom which has the advantages of readily available technology, flexibility in the types of 3D structures to be produced and lowered costs, however, it can be complicated to design and manufacture 3D fabrics in this way [7].

Technical textiles are interdisciplinary in nature; "cross-discipline collaboration between textiles and engineering" were noted to be increasingly commonplace within research and industry by woven textile designer and academic Soden [8]. She also noted that although these types of projects resulted in mutually beneficial outcomes, there were challenges regarding "deep rooted prejudices of both disciplines" and ensuing communication problems regarding "terminology, basic understanding of… specific technical requirements and limitations."

To design technical textiles, the designer needs to have a very good understanding of the yarn and its properties, in particular because much of the 3D woven fabrics are used for the applications such as textiles reinforced composite materials (TRCM) – where both the materials used as the matrix and the reinforcing material (such as textiles) retain their individual properties at microscopic level. Textile composites may be textile structures within polymers, ceramics, or metals [9]. Building upon this knowledge, the ability to conduct mechanical or geometrical modeling of the textiles is paramount.

CAD software becomes essential in this field as geometric modelling of yarn is necessary; “solid volumes representing the approximate bounds of the fibres contained within them” [4, p. 5] for the application in composite textiles is important because it enables:
▪ determination of the mechanical properties of the fabric forming behaviour,
▪ prediction of the permeability of fabrics for processing of composites, and
▪ modelling of the mechanical properties of composite parts and their damage behaviour for use in engineering applications.

3 Some basic principles of CAD/CAM in the woven textile industry

According to Price et al. [10], CAD came to be used in the large textile manufacturing firms in the United States since the 1980s. According to Collier and Collier [11], CAD/CAM is a term often used to cover three areas of activity controlled by a linked computerized system: design, analysis, and manufacture. CAD helps in design and product development and CAM helps in controlling the operations steps of production and equipment. The analysis of design and their translation for the manufacturing system is carried out by equipment that is part of computer-aided engineering (CAE). It is the combination of CAD, CAE, and CAM that make up computer-integrated manufacture (CIM) – otherwise referred to as CAD/CAM [11].

A fully integrated CAD/CAM system implies that the graphic designs developed in the CAD system are translated into numerical information that is analysed by a numerical control (NC) element which enables production controls through computer-generated instructions to computer-controlled looms (Ref. [12] in Ref. [11]). Electronic looms are controlled by a control panel with features that enable the user to save important setting parameters for different fabrics for ease of recall should the operation need to be repeated or amended, thus saving time. Instructions may be printed out and enteredmanually or sent digitally through USB, floppy disks, or email to the manufacturing loom. ScotWeave (a UK-based textile design CAD system) states that the following elements are necessary for a CAD to CAM system to be fully functional [13]:

- accurate printouts with a colour printer,
- obtain printed production data (loom card) with weaving instructions,
- create data to interface with electronic textile machinery, and
- send design by email easily to other sites.

A CAD/CAM system may also link the production stages to orders, sales, production planning and scheduling and sales analysis, etc., via a secure server through an electronic data interchange (EDI) system. EDI is computer to computer communication between trading partners for business documents such as sales invoices or purchase orders in a standard electronic format typically ANSI (for the United States) or EDIFACT (for Europe and Asia) which are further tailored to meet particular industry needs [e.g., for the textiles industry it is the Textile/Apparel Manufacturing Communications (TAMCS)] [14]. As information is exchanged between computers, there is no human handling of information beyond the initial identification of required documents to be exchanged. The process is, therefore, paperless, takes very little time and is error free (e.g., keying in data incorrectly, etc.); this raises efficiencies in the business process in terms of time, cost, and length of the business cycle (i.e., time taken for the business transaction to be communicated) [15]. CAD/CAMsystems may also link their EDI to an enterprise resource planning (ERP) system which moves the business information communicated via EDI through the various stages of production and the manufacturing pipeline to enable timely decision making about the product and production stage to optimize resource and materials efficiencies. The following section provides exemplars of CAD/CAM systems currently in use within the textiles industry.

4 CAD/CAM systems in the woven textiles industry

As noted earlier, the textile industry may be regarded as having domestic and commercial applications (such as apparel or interiors) to industrial and technical (such as geo-engineering, medicine, and heavy industry). There are some nonspecialist software applications that enable a woven design to be created on the CAD system.

LECTRA have developed CAD/CAM systems such as for apparel industry that can also develop knit and weave designs within the CAD function. However, as there is no link to a manufacturing element, the design is saved or printed out (with technical information) to undergo the necessary procedures to make the design manufacturable. The intention, therefore, in this type of approach is to enable apparel designers to express their creative vision or amend/reinterpret a current design that a specialist textile designer may then develop. The following sections introduce and explain some of the features of the specialist textile CAD/CAMsystems. In general, weave software is built up as a series of modules: CAD, CAM, and server systems.

4.1 CAD features

4.1.1 Domestic and commercial textiles

Commonly used weave CAD packages are: AVA, ScotWeave, Textronic, Arahne, NedGraphics, and EAT. Windows is the most common operating platform for the software but Apple Mac and Linux are also used. The designs can generally be read across different platforms, circumventing, as far as possible, technology ‘lock in’. In general, weave software may be able to design for dobby, jacquard, and for carpet designs. CAD systems should provide the following functionalities:

- printout loom cards with all production instructions that may be linked to peripheries such as printers or send instructions directly to looms for manufacture [i.e., links to computer-assisted manufacturing (CAM) processes, most often Bonas or Staubli for jacquard weaving],
- calculating yarn consumption and cost implications as part of the design functions,
- archiving system for data storage, retrieval, sharing and management systems, and presentation methods,
- presentation – such as texture mapping, story boarding, and
- draping functions (to visualize the woven fabric design applied to a product) [16].

Most software packages will provide dobby or jacquard weaving features. Differentiating features tend to be around specialisms such technical textile weaving, colour matching specialisms, or links with retail, examples of which are:

* ScotWeave software has a package for face-to-face velvet and technical textiles, ScotCad (e.g., for the automotive industries, geotextiles, medical textiles, antiballistics, etc.) and has a cross-sectional and 3D visualization feature which enables the weave structure to be viewed from any angle desired to identify any defects in the weave structure.

* AVA is highly regarded within the printed textiles industry and so has sophisticated functions regarding colour matching of yarns to ensure that colour specifications for the designs are maintained throughout the production process.

- Arahne presents its software as the most cost-effective package to be used by industry and educational institutes; it offers the dobby and jacquard together on one software package.
- Textronic, NedGraphics, and EAT software along with dobby and jacquard have a carpet weaving software package which is also capable of being linked to CAM operating looms such as Staubli.
- Textronic features a retail solution (Tailor-I, Try-on, Style me, and 3D showroom) which are mechanisms to show as realistically as possible what the end products may look like for clients and retail consumers.

4.1.2 Heavy industrial/technical textiles

CAD has propelled the technical textiles sector of the industry into prominence. CAD has been developed for the technical textiles sector on a commercial basis by software development companies such as ScotWeave's Technical Weaver or The Designscope Company's EAT (3D Weave and 3DWeave Composite) software. However, as research continues and develops, academic institutes have also been developing software applications from within textiles related or materials departments. The following discussion, therefore, is merely an overview of the key features; it is difficult to provide an in-depth analysis of each of the types of software applications available because each application has been developed in response to a particular product requirement and is outside the scope of this chapter.

The way that CAD is used for technical textiles differs from how it is used within the domestic markets. Many of the functions in the ScotWeave package (yarn costing data, scanning feature, image edit tools, library of over 700 weaves, float checking, auto-drape, fabric finishing, import/export weave data, output instructions directly to the looms, etc.) are of limited value to the technical textile researcher [4].

ScotWeave's Technical Weaver module (ScotWeave Technical Weaver), however, models technical textiles at the mesoscopic scale providing some of the requirements of the technical textiles designer. The different scales of examining textiles have described as: "microscopic scale of the yarn, the macroscopic scale of the woven structure, and an intermediate (mesoscopic) scale of a few intertwined yarns, which defines the unit cell reproducing the whole structure by a periodic translation" [17].

A unit cell has been defined as "… the smallest unit of textile that, when tiled, will recreate the full scale textile" [4, p. 5]. The unit cell needs to be geometrically modeled in order to determine how the yarns are arranged, what the strains on them are and therefore, develop predictions regarding their behaviour (shape forming, porosity, breaking, impact damage, etc.). In ScotWeave's Technical Weaver yarn cross sectional shape and weave pattern can be specified to create a 3D geometrical model.

Various commercial software packages have been produced for designers within textiles composites industries. However, depending on their uses, there may be limitations placed upon the commercially available packages requiring more bespoke software packages, for example, according to Sherburn [4], ScotWeave's Technical Weaver as bought did not enable calculation of mechanical properties and was limited to modelling orthogonal woven fabrics. The necessity to be able to mechanically or geometrically calculate and model yarns have led companies and universities to develop software systems of their own, such as TexGen, WiseTex and TexEng Software Ltd. TexGen [4, 18, 19] and WiseTex [20] were CAD modelling systems to provide predictive functions for fabric permeability and composite mechanical properties. TexGen is a free and open source licenced software (General Public Licensing) and operates on Windows and Linux. WiseTex differs from TexGen in that it models based on the physical properties of fabrics, thus enables the modelling of gaps created when designing the fabric [4]. TexEng Software Ltd. is developed from research at the University of Manchester on technical textiles. It developed and now markets Weave Engineer, Hollow CAD, GeoModeller, UniverWeave, and Structra.

The programmes have been developed as user friendly with commercial applications in mind. Weave Engineer supports speedy and accurate design and manufacture of 3D solid fabric of multi as well as single layer, Hollow CAD, supports design of 3D hollow woven architectures with uneven or flat surfaces when opened up, and can be used in the investigation of lightweight textile composites [7].

4.2 CAM features

4.2.1 Transfer of designs from CAD to the loom

The transfer of the design from the CAD system to the loom for manufacture is of obvious importance and this can take place in several ways. Essentially, the CAM of woven textiles requires three events to take place: (i) the CAD design to be developed, (ii) translation of the design so that the loom can understand the instructions, and (iii) a means of inputting the instructions to the loom to create the textile in the required design.

In its simplest form, a design can be exported (or imported) as a standard image file (such as TIFF, BMP, etc.) and a production ticket (loom card) with full production details can be printed out to be input into mechanical looms. Where electronic looms are used, the loom card can be output as HTML for direct input into the loom via a control panel on the loom as described in Section 6.3. Jacquard weave designs tend to require programmes that will translate the design into the relevant instructions for the loom. For example, ScotWeave's Jacquard Designer programme is a CAD facility for creating jacquard designs, the designs are then sent to Jacquard Looms (the CAM facility in ScotWeave) which translates the design into the appropriate instructions for correct loom settings and parameters for the jacquard loom [13, 16].

4.2.2 Design archive and product data management

All CAD/CAM systems can create, save, store, retrieve, amend, and correct designs created on the CAD system used. Some software systems have developed in-house (intranet) server systems for (i) storage of designs and (ii) production planning.

The system operates as in Fig. 6.1.

A server-based design archive incorporates 3D texture mapping, for draping and product simulation, decoding of weave designs, and produces technical report cards. As the archive is stored within a server, it enables remote working. A designer may be working on a laptop or tablet with their client at a client's premises or perhaps at a trade exhibition, they will be able to create, or, amend designs stored in the archives, CAD system create simulations of the end product, develop bespoke catalogues as well as produce more technical information.

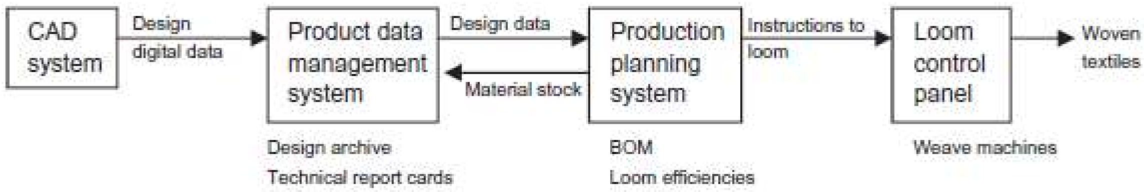

Fig. 1 A generalized server system for design archive and production planning.

In addition, customers may be given access to the archive so that they may have greater flexibility and choice over design of products, without the need to download any software. The server-based design archive is, therefore, a product data management (PDM) system allowing a company greater transparency and control over the product specification. In NedGraphics, the design archive is called 'PDM' system and in Textronic the archive is called Design Integra [21]. The design archive transfers design data and instructions to a production planning server system to which it may be linked. As the production planning system is based on a server, it can connect with several looms and so its role is to transfer data to the right loom at the right time. Ned Graphics and Textronic have developed their own systems. At Textronic, the system is called 'production planning and control' (PPC) while NedGraphics system is called 'loom connection'. Both systems have very similar functions and the following is taken from NedGraphics webpage describing the functionalities of loom connection [22]. Loom connection manages and controls electronic jacquard looms and links it with the design archive. The loom connection also has the following functions:

- tracks status of jobs,
- version management,
- monitors loom efficiency,
- captures, stores, transfers loom parameters,
- adds information to weave jobs, and
- automatically rearranges harness layout.

The system also enables loom operators to retrieve jobs from the server and modify production information. Design management capabilities ensure that, although the adjusted pattern can be merged directly with the original, it cannot be overwritten without notification. Amendments made on the loom controller can be stored directly in the original database and any corrections are automatically incorporated into the production data the next time it is sent over the network. Email notifications can be issued to anticipate production flaws or controller availability [22].
The combination of the PDM (which manages product data information) with the production planning system brings to the company the capability to manage products and processes – that is, product lifecycle management (PLM) within the company. The production planning systems can be linked with any existing planning system. When integrated with an efficiency resource planning system (ERP), the company is connected across the supply chain. Real-time information is available across the whole business with visuals of the product in process to enable quick decision making about efficient and timely deployment of resources or materials.
Internet web-based server technology has been used by EAT (the designscope company, 2018). The design archiving system, 'Designbase Victor' is linked to the 'LoomNet Victor' and offers remote access as well as remote working capabilities.
Looms can be controlled remotely, and several manufacturing plants can be controlled simultaneously. As with other server-based systems, there is multiuser access and multilevel

authorization facilities but, since the framework is Internet web based, it is accessible via a web browser providing faster communications across supply chain partners.

5 The role of CAD/CAM within the woven textile industry

The most obvious benefit of using CAD/CAM is the speeding up of the process of product development and in some areas of weaving CAD/CAM is essential (e.g., in jacquard weaving to avoid mistakes in the complex process of design). There are issues raised through the use of CAD and CAM in product development, manufacture, and supply chain.

5.1 Product development

The weave design process would often take weeks or months to complete as the weave design was first conceived of and drawn onto graph or point paper by the fabric designer and then copied onto board by a painter to the exact and precise colours of the design. This board would be sent to the mill for a sample to be woven for approval by the client. Any amendments would be noted and fed back to the studio by the mill. With the advent of CAD/CAM, the designer can design or decide which yarns will be employed, draw out the weave design in the computer, either print or email (as JPEG or another file) to the customer and make any amendments as required.

Computer screen and printer calibration technology has enabled a ‘real-life/virtual’ sampling technique, although further approvals may still be required before final production commences. Fig. 6.2 illustrates the changes in timing and the closer relationship between customer/client and designer enabling quicker communications and more creative decision making regarding the final product.

CAD/CAM enables the following: quicker and shorter production cycles, reduction of mistakes, value-added merchandize, and direct communication between buyer and designer. As CAD/CAM systems commonly now have draping and texture mapping functions, it is also possible to visualize the end products as the consumer might see them (be they interiors, garments, etc.), thus enabling quicker alterations of designs and decision making throughout the supply chain.

5.2 Manufacture and the supply chain

The use of CAD/CAM is of increasing strategic importance in the supply chain [22a]. The nature of the textiles supply chain has changed from a linear sequential or serial system to a network system. Globalization and its effects have profoundly changed sourcing and manufacturing as well as trading and the market place. To compete, a company needs to have greater flexibility and quicker response. As supply chains have dispersed geographically they have become increasingly dynamic in nature, requiring ever greater communication and networking. Intraorganizational networking has been common place as communication within a company is vital for it to progress. Information technology (IT) has made interorganizational networking increasingly common as different companies begin to form virtually integrated operations to cope with competitive pressures.

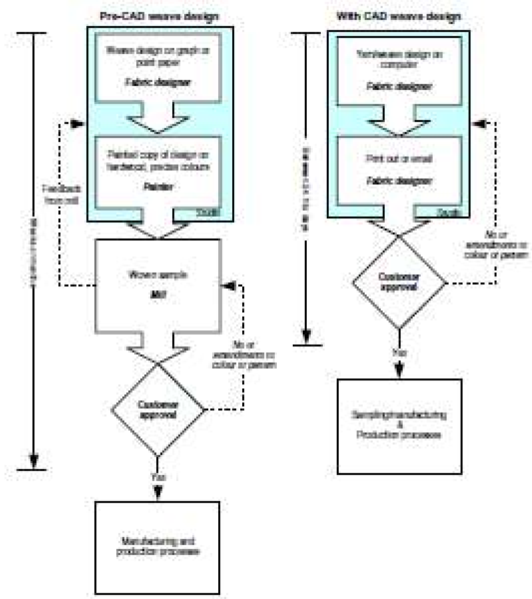

Figure 2 - Weave design before and after introduction of CAD technology. After A. Price, A.C. Cohen, I. Johnson (Eds.), J. J. Pizzuto's Fabric Science, seventh ed., Fairchild Publications, 1999.

Virtual integration differs from vertical integration. Where vertical integration is based upon a single organizations range of capabilities, virtual integration is based upon the most competitive capabilities of several organizations working together in a network as it enables flexibility and responsiveness (Wang and Chan, 2010). CAD/CAM, coupled to enterprise resource and planning (ERP) and, or, systems applications and products (in data processing) (SAP) systems has helped partnering companies in product development across a supply chain to achieve greater and more effective cooperation, communication, and higher productivity with lower costs.

6 Key issues in the use of CAD/CAM for the woven textile industry

6.1 Design

It is possible to scan in a design and reinterpret through the software into a weave design for the client. This can raise issues about the line between interpretation and ownership, which, although too complex for a discussion within this chapter, nevertheless have a significant impact on companies from the legal, financial, and brand reputation perspectives.

6.2 Communication

CAD/CAM, a form of IT, has helped partnering companies in product development through a supply chain to achieve greater and more effective cooperation, communication, and higher productivity with lower costs. Therefore, use of the same IT and CAD/CAM systems helps companies to understand each other better (e.g., product specifications are in the same 'language') but raises issues that have to be addressed in order for the network to continue to flourish: trust, shared resources and competencies, agreement on size of network (for the market size and its constraints), optimization of the global supply chain and, in some cases, possible technology 'lock in' whereby the use of a particular platform is necessary to enter the virtually integrated network.

6.3 Expertise and skills required for woven textile CAD/CAM

Weave designers need to be multiskilled and understand both the supply and cost issues, the technicalities of the production such as fabric analysis, drafting the pattern, tensions and yarn lengths required as well as CAD packages. Skillfast UK (http:// www.skillfast-uk.org/) conducted a survey of skillsets that the fashion and textiles industry felt were necessary for a variety of roles within the industry and itemized those required of the weave designer (Table 6.1). Most textiles companies require new employees to be have a working knowledge of CAD/CAM, even though they may provide some in-house training from the software providers. Most new textile designers will learn their skills from universities or colleges of textiles. To become adept in the use of CAD/CAM, one must understand the principles of weaving by hand, this will often take a year or so before the application of CAD/CAMcan be used to develop woven designs from. To develop skills in CAD/CAMfor technical textiles markets requires further study as this requires not only fundamental understanding of fibre properties and CAD/CAM but skills in mathematical modelling techniques that be applied to leverage the fibre and fabric properties. The level of specialist knowledge and expertise that a technical textiles CAD/CAM weaver would require could be approximated to a Master level of study or PhD, that is, this is a highly specialized area that is to be found in the R&D areas of companies or universities.

There are several weave CAD/CAM software packages available to both industry and education, and to be a credible weave designer, especially to enter the larger companies, a working knowledge, if not some degree of expertise, in using CAD/CAM has become a necessity.

6.4 Costs incurred in using CAD/CAM

A term most often associated with CAD/CAM is 'investment' and it is often the larger companies who are suppliers or part of a global network that spend the most and benefit from this. The costs of software are varied and cannot be estimated in a simple manner. The costs of buying in CAD/CAM may vary between about £1000's to multiples of £10,000's. Factors that influence the actual and final cost include the following:

- The licence to use the software (and numbers of each person requiring the use would need to have the licence).
- If 'floating' licences and 'keys' are required (to use in situ or on lap top away from the office).
- Training to use the software:
- trainer's daily rate,
- travel for the trainer to come to the studio, and any stay and sustenance.
- Computer platforms to support the use of the software (and what are they compatible with).
- Peripheries (e.g., printers, links to CAD/CAM at other sites, links to factories, etc.).

* Servers to store or access the information.

* If there is an annual subscription or payment for annual software update.

7 New products/markets and future trends through CAD/CAM

While the textiles industry has gradually become ever more mechanized and reliant on the use of CAD/CAM architecture of its production plants, the area of technical textiles has been growing and is now a means of competitive advantage for saturated textiles producing economies. This sector has been described as a growth area, and, indeed, a report in 2006 stated that the technical textiles sector was a dynamic and buoyant one with an annual growth of 5% [23, 24], however, because of the problems in defining the sector, measuring the size of the market is a difficult one. Kowalski and Molnar [25] described some of the efforts to try to estimate the size of this sector which include dividing the market into (i) traditional, (ii) technical, and (iii) technical and mixed textile product categories.

- Traditional textiles being: silk, cotton, wool, and other vegetable textile fibres.
- Technical textiles: man-made filaments made of or containing nylon, polyamide, polyester, polypropylene, viscose; man-made staple fibres and impregnated, coated, or laminated textile fabric (e.g., various man-made tyre cord fabrics).
- Technical and mixed textiles products: products manufactured from both traditional and man-made fibres such as: wadding, felt, nonwovens, yarns, twine, cordage, carpets, knitted, or crocheted fabric.

Despite these problems of categorization, they noted that exports from China and India are increasingly technical textiles. According to Byrne [6] major, influential textiles industrial exhibition, Techtextil, was launched in 1985 which provided a taxonomy that has been used to describe the various industry and market sectors that technical textiles are applied in:

- Agrotech – agriculture, horticulture, forestry, and aquaculture textiles.
- Buildtech – building and construction textiles.
- Clothtech – technical components of shoes and clothing, for example, linings.
- Geotech – geotextiles and civil engineering materials.
- Hometech – technical components of furniture, household textiles, and floorcoverings.
- Indutech – textiles for industrial applications, for example, filtration, conveying, cleaning, etc.
- Medtech – hygiene and medical products.
- Mobiltech – automobiles, shipping, railways, and aerospace.
- Oekotech – environmental protection.
- Packtech – packaging materials.
- Protech – personal and property protection.
- Sportech – sport and leisure.

Notwithstanding the actual size and share of the textiles market, CAD/CAM knowledge and expertise has had a powerful influence on the technical textiles sector. Of increasing interest is the composite textiles (textile-reinforced composite materials) which have been described as "multiphase materials within which the phase distribution and geometry have been deliberately tailored to optimize one or more properties" [9, p. 264] and as "such that they do not dissolve or merge completely into each other" [26, p. 1]. Ogin [9] continues to describe how textile composites are formed of a matrix (which may be polymers – such as epoxide, polyester, nylon – metals) reinforced by a fibrous material – such as carbon fibres, glass fibres, boron, ceramic, aramid, or textiles. Textiles have been used in industrial composites for over a century [26] and therefore, it is a mature application. However, the use of CAD/CAM, advances in computational modelling and mathematical analysis techniques have seen an increasing replacement of other

fibres with textiles. Textiles have the advantage of cost, enhanced by its affinity to being processed with other materials for adequate or improved mechanical properties. Woven textile composites have been used very successfully in aerospace because they are light, have good drapeability, allow complex shapes to be formed without gaps and costs are lowered as biaxial fabrics have replaced two layers of nonwoven fabrics. The ease of handling of the textiles has enabled automation. Woven textiles also have the advantage of increased resistance to damage from impact and compression strength. The disadvantage of using woven textiles is their lower stiffness and strength than nonwoven textiles.
Technical textiles require high input of R&D efforts as well as new technology and has been advanced through the development of user-friendly software system for designing woven structures based on the mechanical and geometrical modelling with the aim of creating close-to-reality geometrical models for analysing mechanical, fluid, and thermal properties, essential in systems such as predicting fluid filtration performance through filtration textiles, 3D hollow composites for energy absorption, shock absorption or antiballistics performance, etc. [7, 23].

8 Conclusion

Efforts in textiles woven CAD/CAM applications are continuing in the areas of colour, drape, yarn modelling which can have applications in either the commercial or technical areas. Linked up with other digital applications, there are possibilities for visualizing, characterizing, modelling, and predicting textiles properties with a view towards manufacture. Traditional jacquard designing, reliant on the skills of craftsmanship of freehand design for copying through the mechanical weave loom, is assisted through the application of CAD/CAM systems. Digital jacquard technology incorporates CAD and digital production technology (electronic jacquard machine and new-generation weaving looms). This enables total digital control of design and production, and all data from design to weaving are processed, controlled, and transmitted via the computer. This has enabled jacquard fabrics with photo-realistic effects with a mega-level colour number on the face of the fabric, raising the potential for security applications of this research [27]. Advances in modelling dry drape of textiles have their applications in the development of predictive modelling for 3D woven technical textiles (composites), garment design and manufacture and reverse engineering of weave structures from samples of fabric, useful in security applications [28].

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