Computer-Assisted Total Material Design of Woven Fabrics for Apparel Use :

Part 2 : System Development and Application Example

M. N. Suresh*, T. Matsuo**, M. Nakajima**, M. Inoue***, T. Harada****

Abstract

In part 1 of this series, the fundamental logical structure of the computer-assisted total material design system for designing woven apparel fabrics was dealt. The executional logic, related databases and other components are discussed to perform the design task. This part aims to present the detailed computer algorithmic flow toward the development of a computer-assisted 'total material design system' (TMDS). The Paper starts with a brief introduction discussing about the importance and procedures of the designing. Developmental aspects of the design system and its criterions are explained. The functional architecture of TMDS is also given. Further, the executional procedure of the logic of TMDS has been tracked through a certain simple design problem. Some practical application examples of designing worsted fabrics are dealt according to the developed total material design logic in detail.

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1. Introduction

Overall, as far as textile product is concerned, viewing the logic of design in the perspective of overall engineering process is important. This involves several phases: conceptualization, research and development, design, manufacturing, testing, maintenance, and marketing. During this process, people from various disciplines interact to produce a product. Broadly, the types of textile product designing methods can be classified as follows¹⁻³⁾.

- Color/pattern Design and Material Design
- Partial and Total Material Design (TMD)
- Explorative/creative Design and Modification/adjustmental Design

Also, the material designing system can be summarized as shown in the Fig. 1 which is self explanatory^{1,3)}. On the other hand, the apparel product designing generally belongs to modification/adjustmental design¹⁾. The procedure is

to modify or adjust only one or a set of structural or functional parameters for a new design target in comparison with certain previous products. This often involves a kind of redesigning technique, however, repetition of the design effort with modification to various processes may lead to conceptually distinct alternative solutions. If

Fig. 1 An overview of material designing system for textile products

*Department of Textile Science, Kyoto Institute of Technology, Matsugasaki, Kyoto, **Member, ***Toyobo Co., Ltd., Mie Factory, Nakagawara, Yokkaichi-shi, ****Toyobo Co., Ltd., Katata Research Center, Otsu

the number of possible modifications is small, then an exploration of new combinations may be feasible. Also, this type of designing can effectively utilizes different databases⁴⁾ that tend to accelerate the use of CAD leading to systematic designing procedure.

In part 1⁵⁾, an attempt was made to define and categorize the fundamental elements of the computer-assisted 'total material design system' (TMDS) in more generalized format. The main sections related to this are : the user interface, the five design phases starting from conceptual design up to manufacturing design, and different types of databases. Also, the logic of the total material design with an optimization procedure was described.

This part aims to present the detailed structure toward the development of computer-assisted system. The functional architecture of the system and its executional procedure with a simple example is dealt. An application example is also provided based on the five design phases.

2. Functional Architecture of Computer-Assisted Design System for TMD

Overall, the development of computer-assisted design system is a process characterized by interactive decision making between the designer and computer so that the design objectives are satisfied under various conditions. This process involves the procedures of constant verifications, identifications, formulations and satisfying of design conditions or constraints. All these conditions/constraints are continually added, deleted and modified throughout the designing process. Also, the design elements and their parameters are usually rather complex and often numerous^{1, 6-8)}.

The process of development of any computer-assisted systems for designing textile products can be carried out in two phases, which is typically illustrated in Fig. 2. In this process, the 'Phase-1' is to construct the main and sub mod-

Fig. 2 Developmental procedure of computer-assisted systems

ules where the logic of the designing procedure will be structured. In which, the system initialization will be done first, then the designing of a product through various sub processes will be done, and then display/output will be determined. At this stage, the results of the trial procedure will be scrutinized and evaluated by the designer/domain experts. Also, possible corrections will be made according to the predicted objectives. After number of trials, a detailed evaluation will be done in the 'Phase 2' followed by corrections. Finally, the original modules will be corrected with a suitable validation of the developed modules. Also, these developments are based on some general assumptions : the system will be used by the designer or domain expert, and the databases have to be created for the specific domain according to the system environment.

Fig. 3 shows the proposed functional architecture of the TMDS. In which, the main components are :

- a) a user interface for the interactive activity between the designer and the computer
- b) an inference module, in which all modules of the designing phases and some control programs in the form of queries are stored. This uses 'Turbo prolog' language which is suitable for developing query structure⁹⁻¹¹⁾. This module controls all other modules to carry out the complete

Fig. 3 Functional architecture of TMDS

design process starting from the conceptual design phase up to the manufacturing method design phase.

c) a priority/allowability module written in 'C' language¹²⁾ uses the 'Analytical Hierarchy Technique'¹¹⁾ to fix the priorities/allowabilities of the design elements. The priority will be synthesized in pair-wise comparisons of the design elements.

d) a suitability judgement module which works to check the suitability of design element values. It includes the optimization part in 'C' language that uses 'Genetic Algorithm'¹⁴⁻¹⁶⁾. The part is incorporated for complex design situations.

e) a knowledge-based query structure which uses 'Turbo Prolog' in the form of rules and facts, and uses scientific knowledge and/or expert advice. Some examples related to the query structure are dealt in section 3.

f) some databases to be created based on the relational database structure (refer Fig. 2 and 3 of Part-1). Although 'Turbo Prolog' is used for creating databases, which serves the purpose for developing simple/pilot level applications, 'dBASE-IV' is more suitable for creating databases when there are too many data types has to be structured.

3. The executional procedure of the logic of TMDS

The design process operates through five phases according to the frame and the logic of the TMDS as explained in part-1³⁾. The executional procedure along with its computer

flow of the TMDS logic has been tracked through a simple example.

a) General processes before the designing stage :

Before going to the core of the process, one has to understand the customer-manufacturer activities in textile business. The activities are further related to marketing, consumer reaction, place, environment, and so on. The orders/purchasing in textile business at top level management in a case generally may involve following cases¹⁷⁻¹⁸⁾ :

1. Customer gives some specifications/ideas to manufacture in reference with other products
2. Manufacturer tries to convince the customer by referring to his best samples
3. Customer asks some requirement to be fulfilled according to his perspectives
4. Manufacturer tries to fulfill the customer's requirements

b) Design problem (as an example) - designing of worsted fabric for apparel use :

The customer wants the manufacturer to produce the fabric used for formal black wear for men which should be something different from the usual formal black wear.

The basic schema attributes among many attributes used for this example is given in Table 1. At first, the system starts with initializing INF_MOD to start the designing process in five hierarchical phases^{1, 2, 5, 9)} as given below.

#start

< conceptual design phase

Table 1 Schema attributes used for application example

Schema attributes used in the computer algorithms	
REF	-reference sample module (d)
CPD	-conceptual design module (a1)
FED	-function/effect design module (a2)
BSD	-basic structure design module (a3)
BMD	-basic manufacturing design module (a4)
DMD	-detailed manufacturing design module (a5)
INF_MOD	-inference module (b1)
PRI_ALLO	-priority/allowability module (b2)
SEN_EXP	-sensory expression module (b3)
SUT_FAB	-suitability module (b4)
COST_EST	-cost estimation module (b5)
FED_EST	-function/effect estimation module (b6)
FACT_DB	-factual/historical database (c1)
SCI_RDB	-scientific relational knowledge database (c2)
IND_RDB	-industrial relational database
BSD_DB	-database for selecting structure (c3)
COST_DB	-database for costing (c4)
MANF_DB	-database for selecting processing parameters (c5)
REF_DB	-reference fabric database (C1) which is a part of FACT_DB
INFO_BASIC	-general basic information related customer/product/etc.
A_BSD	-assumptive basic structural design module
A_BMD	-assumptive basic manufacturing design module
MAN_DB	-database related manufacturing methods and processes
prod_name	-name of the product
cust_name	-name of the customer
usage	-internal/external usage of the product
mat_type	-type of material [ex wool/polyester/cotton, etc.]
prod_type	-product type [men/women/children/etc.]
ref_sam	-a particular reference sample
prod_fet	-product feature
app_fab	-appearance of fabric
hand_fab	-hand of fabric
mech_fab	-mechanical properties of fabric
dime_fab	-dimensional properties of fabric
phy_fab	-physiological properties of fabric
basic_struct	-initial structural design elements
assum_struct	-assumptive structural design parameters
basic_mnfc	-initial manufacturing design elements
assum_mnfc	-assumptive basic manufacturing design parameters
opt_eff	-optical effect of the material

(a1-a5, b1-b6, c1-c5 and d are the symbols used in part-1 of this series)

function/effect design phase
basic structural design phase
basic manufacturing design phase
detailed manufacturing design phase >

The designer can now consider these phases according to his choice to perform the design task. The first phase is to deduce the concept of the product to be produced. At first, INF_MOD contacts INFO_BASIC to fix some basic general information about the product name, type, customer, etc., as follows.

```
#basics
< prod_name : [regular/new]
  cust_name : [regular/new]
  usage : [domestic/abroad]
  mat_type : [wool/cotton/polyester/blends/.....]
  prod_type : [apparel/household/industrial/
               medical/sports/.....] >
```

If the prod_name and cust_name are regular,

the data can be retrieved from INFO_BASIC and input can be fixed, otherwise new information has to be fed. The same procedure is adopted to fix the usage, mat_type and prod_type. Then the designer can decide or confirm each choice and fix the basic informations. With this, the INFO_BASIC fixes the basic information by asking queries. The computer flow related CPD is given in Fig. 4. The example is :

```
#basics
< prod_name : //new//none//
  cust_name : //new//none//
  usage : domestic
  mat_type : wool 100%
  prod_type : apparel//men//formal-wear >
```

The next step in this phase is to find suitable ref_sam to assist for realizing the concept. Sometimes the customer may decide the concept of the product to be designed, or in an another case manufacturer can search for a suitable ref_sam. The CPD is then activated to contact REF_DB to retrieve the list of suitable ref_sam closer to the customer's requirements. Here the selection of ref_sam is very important, if a correct ref_sam among the group of identical reference fabric samples is selected then the differences in other functional and structural parameters to be designed are rather less. This makes the design process much easier. In the present example, the ref_sam is the usual black wear. The synthesization idea will be made in comparison with this ref_sam. The basic elements to synthesize the concept are appearance, hand, and other properties such as mechanical, physiological, dimensional, etc., as shown in Fig. 5.

In the next step, concept will be synthesized through SEN_EXP module. If the ref_sam is at hand, the synthesization will be much easier. Meanwhile SEN_EXP fixes the difference between the idea formed by the ref_sam and the criteria/requirement/imagination of the target/new product by asking queries to the designer. Once all the queries against the ref_sam were fulfilled then the CPD module provides the con-

Fig. 4 Computer flow of initial conceptual design phase

Fig. 5 Computer flow of conceptual design phase

clusion. Otherwise, the module repeats the pro-
ceduer for retrieving the new set of ref_sam to
fix the concept. Finally, the conceptual design of
the present example will be concluded as fol-
lows.

```
#concept
< prod_name : //new//none//
  cust_name : //new//none//
  usage     : internal
  mat_type  : wool 100%
  prod_type : men's formal black wear
  ref_sam   : usual formal black wear
```

```
prod fet   : deep black-soft hand
cost       : a little higher cost
            is tolerable >
```

In this phase, two important things have been
settled to realize the function/effect design : one
is the concept of the product to be produced and
the other is the suitable ref_sam to make the
design process more simple.

As a second phase, the functionalities of the
new concept of the fabric have to be designed.
The method and its computer flow of fixing FED
elements has been illustrated in Fig. 6. In this

Fig. 6 Computer flow of function/effect design

phase, the conclusions of CPD will be transformed to the FED module. Then the FED design element list provides general functions to be designed as follows ;

```
#functions/effect
< app_fab : [color/drape/luster/texture/optical
             effect/.....]
  hand_fab : [bending/compression/surface friction/shearing/.....]
  mech_fab : [tensile/tearing/.....]
  dime_fab : [shrinkage/pilling/deformation/.....]
  phy_fab : [air permeability/sweat transport/.....]
  dyeing : [dyeability/color fastness/.....] >
```

The next step is to design the required functional parameters sequentially comparing with the ref_sam. At this stage FED contacts FACT_DB to obtain the facts of each design element of ref_sam. Table 2 shows a sample FACT_DB of some design items. In the table, 'A' to 'E' are the five different ref_sam's. ref_sam 'C' is the selected suitable ref_sam for this example.

Further, FED contacts SCI_RDB and SEN_

EXP where the data is created in the form of knowledge-based rules/facts to fix the definition of different features of fabrics such as appearance, hand, etc. For this example, the deep color of the fabric can be conceived as follows ;

```
Knowledge-based rule for app_fab (color) :
< IF the color is black
   normal contrast
   used for ordinary structure (plain)
   used for usual black wear
   THEN L-value must be between 14-15 >
< IF the color is black
   significantly deeper than usual one
   above normal contrast
   used for ordinary structure (plain) /other
   THEN L-value must be between 11-12 >
```

These types of knowledge-based rules can be created with the help of experts advices or research results. Also, these can be used as forward or backward tracking to fix the functions more precisely. The creation of knowledge-based rules by the panel of experts has to be done for a

Table 2 A sample factual database of some of the items related to FED

	samples items	A		B		C		D		E	
property		wa/d	we/d	wa/d	we/d	wa/d	we/d	wa/d	we/d	wa/d	we/d
KES	B (gf·cm/cm)	0.10	0.08	0.10	0.08	0.11	0.09	0.12	0.09	0.12	0.10
	EMT (%)	4.85	6.36	4.73	9.77	5.13	8.51	3.95	0.61	3.67	7.97
	G(gf/cm.degree)	0.58	0.52	0.48	0.47	0.51	0.38	0.38	0.61	0.79	0.73
	2HG (gf/cm)	0.47	0.43	0.47	0.39	0.54	0.43	0.43	0.25	0.49	0.54
	2HG5 (gf/cm)	1.18	1.03	1.08	0.95	0.99	0.76	1.35	1.41	1.66	1.61
Other properties	strength (kgf)	44.5	32.0	42.0	32.0	40.0	30.0	30.5	21.5	45.8	24.0
	elongation (%)	48.6	38.4	31.3	38.0	36.7	38.7	31.3	27.0	37.0	28.4
	shrinkage (%)	< 3		< 5		< 2		< 3		< 4	
	pilling grade	5		5		5		5		5	
		wa/d-> warp direction					we/d->weft direction				

particular domain suitable to the respective industrial environment. In this way, appearance function can be fixed as follows :

```
#app_fab (color)
<  L-value      : 11-12
   drape        : same as ref_sam
   luster       : same as ref_sam
   col_fast     : good
   others       : same as ref_sam >
```

For Hand functions, the FED module directly

<i>Items</i>	<i>warp direction</i>	<i>weft direction</i>
$B(\text{gf. cm}^2/\text{cm})$	0.11	0.09
$G(\text{gf}/\text{cm. degree})$	0.51	0.38
$2HG(\text{gf}/\text{cm})$	0.54	0.43
$2HG5(\text{gf}/\text{cm})$	0.99	0.76

provides the 'ref_sam C' data as follows.

#hand_fab

Further, FED initiates PRI_ALLO to settle the priority/allowable range among the design parameters. The main aim of providing priority/allowable range is to simplify the design procedure by selecting only few elements depending upon their significance and relevance based on the objective rankings. Each functional parameter can be designed by feeding new suitable design parameter value or providing the parameter allowable range/priority, or taking the design parameter value of ref_sam as it is based on the concept of the target product. The same procedure can be adopted to fix other design elements also. In this example, since the concept of the product is deep black keeping soft hand, the priority/allowability and suitability have to be settled only for few design elements, which can be done by the designer's experience by synthesizing the ranking of the priority elements through pair-wise comparison between the two design elements¹³⁾ (example : app_fab and hand_fab design parameters). Here, L value (app_fab) may take the first priority. B, G, 2HG, 2HG5 (hand fab) may take second, third, fourth,

and fifth priority respectively. Nevertheless, the other design parameters value can be kept as the same as the ref_sam. If the parameters to be designed are more in number then prioritization and suitability/optimization have to be done scientifically. The basic idea of this is to provide rankings to the design elements by creating hierarchy of the focus/target of the product, intended criterions of the product to be realized and the design elements to be ranked, then the suitability/optimization can be analyzed only for the elements of highest level of priority²⁰. This will be dealt in detail in the next part of this series. At this stage, the tolerable/expected cost function range should also be fixed by the designer/manufacture in comparison with ref_sam. Finally, the conclusions made by FED can be given as :

#functions/effects

```

< app_fab : [color (L-value : 11-12)
drape                                     : same as ref_sam
luster                                   : same as ref_sam
opt_eff                                 : low refractive index
others                                  : same as ref_sam]
hand_fab : [ B (gf. cm2/cm)    0.11  0.09
                                     (warp-weft direction)
G (gf/cm.degree)  0.51  0.38
                                     (warp-weft direction)
2HG (gf/cm)       0.54  0.43
                                     (warp-weft direction)
2HG5 (gf/cm)      0.99  0.76
                                     (warp-weft direction)
                                     |           |           |
                                     |           |           |
cost : [ < 10% up (ref_sam) ]
mech_fab : [.....same as ref_sam..... ]
dime_fab : [.....same as ref_sam..... ]
phy_fab  : [.....same as ref_sam..... ]
dyeing   : [.....same as ref_sam..... ] >

```

The same procedure is repeated number of times to fix or redesign the FED element more precisely.

The third and fourth phases are to settle the basic structural and manufacturing method design. Fig. 7 provides the procedure and the

Table 4 A sample factual database of some of the items related to BSD

Itmes	A		B		C		D		E	
	warp	weft	warp	weft	warp	weft	warp	weft	warp	weft
fiber thickness (μ)	18.2	21.1	19.6	20.9	19.2	20.8	17.8	20.2	18.9	20.7
yarn count	2/55	2/55	2/58	2/56	2/60	2/60	2/66	2/40	2/45	2/37
density/10cm	316	256	314	262	314	276	282	238	302	262
twist ratio	1.86		1.47		1.19		1.27		1.62	
areal density g/m ² (fabric)	200		240		230		197		258	
fabric surface	flat		flat		flat		flat		flat	
fabric structure	ordinary		ordinary		ordinary		ordinary		ordinary	

data from FACT_DB for fixing the new design values as shown in Table 4. The related design parameters other than color and soft hand such as fiber thickness, count and twist, etc., are taken as the same as the ref_sam. The conclusions of A_BSD are as follows.

#assum_struct

< fiber [fiber thickness (μ) : 19.2-20.8 (warp and weft)]
yarn [count : 2/60-2/60 (warp and weft)]
twist ratio : 1.19
fabric [structure : ordinary worsted fabric structure]
fabric : less flat surface
treatment : thin layer of resin coating having low refractive index
density/10cm : 314-276 (warp and weft)
weight/inch² : 354
areal density g/m² : 230 >

In the next step, suitable manufacturing method has to be realized for the obtained A_BSD conclusions. The importance of this phase is to select related suitable treatment methods, and finishing methods, etc., to realize the basic structural design parameters including tentative cost estimation comparing with the ref_sam. The design parameters value of A_BSD module will be transformed to BMD. BMD will then contact A_BMD and MAN_DB, where the data related with manufacturing methods related to fiber,

yarn, fabric and their related processes are stored, to fix a tentative manufacturing method to realize the elements of A_BSD. Like in other design phases the BMD provides a list of general manufacturing functions related to the process and its process parameters, and treatments items as follow.

#basic_mnfc

< fiber processing [{mixing/top making/dyeing/treatment.....}]
yarn processing [{spinning/winding/dyeing/treatment.....}]
fabric processing [{drawing/sizing/warping/weft preparation / weaving dyeing / finishing.....}]
processes [{treatments/coating.....}]
process parameters [{spinning/weaving/dyeing/finishing.....}] >

In this phase, only suitable special process and functions to achieve the deep black and less flat surface are rather important. Other design elements concerning manufacturing processes can be taken as the same as ref_sam. Further, A_BMD contacts SCI_RDB and IND_RDB to conceive related process methods such as : the production of deep black fabrics requires suitable pretreatments such as chlorine treatment to reduce shrinkage, resin treatment for maintaining low refractive index and high dye uptake, mild steam setting to control the flatness of yarns, and fabric dyeing, etc. Finally, A_BMD provides the abstractive basic manufacturing method design as :

```
#assum_mnfc
< fiber processing [{.....same as ref_sam.....}]
  yarn processing [{.....same as ref_sam.....}]
  fabric processing [{.....same as ref_sam.....}]
  processes [treatment 1 : chlorine treatment
             treatment 2 : coating by thin layer of
               resin having low refractive index
             dying : fabric dyeing
             'setting : mild steam setting]
  process parameters [{.....same as ref_sam.....}]
>
```

Based on these informations COST_EST will carry out the cost estimation through COST_DB where the costing data related to required/additional manufacturing methods/processes are stored. In this illustrative example, the tolerable/expected cost function range compared with the ref_sam was less than 10% increase. The estimation will follow the procedure explained in part-1⁵⁾, Fig. 8 and the tentative cost function will be calculated using COST_DB. For this example, the estimated cost is around an increase of 8% compared with ref_sam which falls within the tolerable range of designer/manufacturer.

Meanwhile, A_BMD tries to reestimate the functionalities more precisely in contact with FED_EST and SCI_RDB/IND_RDB to realize the assumptive BSD. Finally, SUT_FAB will be activated to check the suitability of A_BSD and A_BMD elements based on the procedure explained in part-1⁵⁾, section 5. If the design parameters obtained from the A_BSD and A_BMD are within the tolerable range including cost functions of the criteria function J, then the A_BSD and A_BMD will conclude the final results. In the present example, the conclusions of A_BSD, A_BMD and COST_EST elements are lies within the tolerable range. Especially the estimated cost is around 8% that is lesser then the tolerable/expected range of designer/manufacturer. In some cases the estimated cost may exceed the tolerable/expected cost. If it is acceptable for the designer/manufacturer then the BMD will be concluded, otherwise the same procedure will be

repeated number of times until J value is satisfied.

Also, if there are any changes or modifications required during any design phases, the designer can redesign the specified design element through iterative processes. Finally, the BMD information will be transformed to DMD for designing the detailed manufacturing method, which can be achieved by fixing more precise manufacturing design elements including a detailed estimation of cost function similar to BMD. Also, decision about the process parameters such as the important settings related to machines, treatments, and finishing methods, etc., can be obtained in DMD with the help of suitable SCI_RDB and IND_RDB to carry out the manufacturing process effectively. In this example, DMD has not been dealt in detail because of the complexity of the real manufacturing process stages, and has to be done at the industry level. The final design description sheet obtained through this logic can be given as follows. Only, necessary design elements and their parameter values of this design example are given to illustrate the sample outcome of the result of TMDS.

#end

< product features

```
product name : new/none
customer name : new/none
usage        : internal (domestic use)
material     : wool 100%
product type : men formal wear (black)
```

conceptual design phase

```
-comparing to ref_sam
**deep black formal wear
  -deeply darken than usual black wear
**keeping soft hand (pliable)
**a little higher cost is tolerable
```

function/effect design phase

```
**L-value          : 11-12
                    : good color fastness
*B (gf.cm2/cm)      : 0.11-0.09
                    : (warp-weft direction)
*G (gf/cm.degree)  : 0.51-0.38
```

	(warp-weft direction)
*2HG (gf/cm)	: 0.54-0.43
	(warp-weft direction)
*2HG5 (gf/cm)	: 0.99-0.76
	(warp-weft direction)
-EMT%	: 5.13-8.51
	(warp-weft direction)
-color fastness	: good
-strength (kgf)	: 40.0-30.0
	(warp-weft direction)
-elongation (%)	: 36.7-38.7
	(warp-weft direction)
-shrinkage (%)	: < 2
-pilling grade	: 5
*cost	: < 10% up
basic structural design phase	
*fiber thickness (μ)	: 19.2-20.8
	(warp and weft)
**fiber surface	: thin layer of resin
	coating having low refractive index
*count	: 2/60-2/60
	(warp and weft)
-twist ratio	: 1.19
-structure	: ordinary worsted fabric
	structure
**fabric surface	: less flat surface
**dyed structure	: high dye uptake
-density/10cm	: 314-276
	(warp and weft)
-areal density (g/m^2)	: 230 (fabric)
basic manufacturing design phase	
**treatment	: chlorine
**coating	: resin (this is of low
	refractive index with suitable con-
	dition to realize thin layer coating)
**setting	: mild steam setting
	(to keep less flatness)
**dyeing	: fabric dyeing (by selec-
	ting black dye stuff of high color
	fastness to obtain high dye uptake)
**cost	: 8% up
	(tentative estimation)

detailed manufacturing design phase	
(not given)	
[	- taken same as ref_sam
	* parameter to be noted
	** changed design parameters]
>	

4. Concluding remarks

In part-1, the fundamental logical structure of the TMDS, which works in five hierarchical phases, and its components functions are discussed. Also, the idea of utilizing the reference sample and suitability function are proposed to make the design task more simple.

This part is concentrated mainly toward the development of the computer-assisted TMDS with a special reference to the apparel fabrics, where not much work has been done. The overall system development and the functional architecture of TMDS have been presented. Also, a simple example of designing worsted fabric has been tracked through the executional logic of the system. In the illustrative example, designing method has been explained for fixing only the appearance, hand and cost functions for the sake of simplicity to follow the executional logic. On the other hand, the usual designing will generally pose complicated concepts and more functions to be realized. In this situation, the developed procedure and logic of TMDS will be more suitable to assist the designer more scientifically. However, a special effort has been made to structure the TMDS logic suitable to the computer environment. Although the development of TMDS has been presented only for designing worsted fabric as a small range application, the similar methodology can be applied for designing other products also.

The priority structures and suitability function along with optimization method²⁰⁾ will be discussed more in detail with examples in the next part of this series. Also, the software details and structure of the pilot version will be discussed in our later part.

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