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Analysis, Modeling and Generation

of Traditional Lao Woven Textile

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Zusammenfassung

Traditionelle laotische Textilien sind reich an religiösen Motiven. Die Motive und Muster auf den Textilien reflektieren Traditionen, Glauben und Existenzgrundlage der Menschen. Die aus dem Spiel mit Motiven und Mustern erzeugte Kreativität stellt ein Kulturerbe dar, das unbedingt bewahrt und geschützt werden muss, bevor es erlischt. Die Struktur von laotischen Motiven und Mustern ist kompliziert, aber bei den Webprozessen werden immer noch traditionelle Techniken und einfache Webstühle verwendet. Daher kostet es viel Zeit einen Webentwurf auf dem Webstuhl zu erstellen, und der bereits verlorene Teil an Webentwürfen ist sehr hoch. Bei industriellen Textilien hingegen werden zur Herstellung von Stoffen elektronische Webstühle und digitale Webentwürfe verwendet, die sich für schnelle Produktion eignen, denen es aber an komplizierten traditionellen Mustern mangelt.

In Folge dessen haben wir in dieser Untersuchung verschiedene wissenschaftliche Algorithmen zur Digitalisierung von Motiven, Mustern und Webentwürfen von laotischen Textilien untersucht, um die Lücke zwischen der traditionellen und der modernen Webtechnik zu schließen und um die Design- und Webprozesse zu optimieren. Wir haben drei Laos Textil (LT) Designmodule zur Digitalisierung entwickelt, die zu internationalen Standardformaten hinführen, und die sowohl für Handweber als auch für Webmaschinen verständlich und verwendbar sind. Das Modul LT-Tieup stellt Motive und Muster für den Entwurf zur Verfügung. Das Modul LT-Weave dient der Motiv- und Mustermodifikation und das Modul LT-Design dem Textildesign und der Visualisierung. All die digitalisierten Motive und Muster werden in unserm Online-Repository archiviert, um das Kulturgut zu bewahren. Das Online-Repository ist ein Werkzeug zum Speichern von Webentwürfen und zur Kommunikation unter Wissenschaftlern sowie Webern und Experten des Kulturerbes. Die Ergebnisse unserer Untersuchungen zeigen, dass unsere Vorgehensweise die Lücke zwischen traditioneller Weberei und der digitalen Webrepräsentation schließt, und dass das Ziel unseres Projektes erreicht wird.

Abstract

Traditional Lao textiles are wealth in religious motifs, the motifs and patterns on the textiles reflect traditions, beliefs and livelihood of people. The creativity in playing with motifs and patterns represents valuable cultural heritage on clothes that seriously needs to be preserved and protected before it is depleted. The structure of Lao motifs and patterns are complicated, but weaving processes still use traditional techniques and simple floor-loom. Therefore, it takes a lot of time for making a weave-draft on the loom and percentage of losing weave-drafts is very high. In contrast, industrial textiles use electronic loom and digital weave-drafts to produce fabrics, which are suitable for fast production but lack complicated traditional patterns.

As a result, in this research we investigated different scientific algorithms for digitizing motifs, patterns and weave-drafts of Lao textiles in order to fill the gap between traditional and modern weave techniques, and to improve processes of design and weaving. We developed three design Lao Textile (LT) modules for digitizing leading to international standard formats which are understandable and usable for both hand-weavers and weaving machines. The LT-Tieup module provides motifs and patterns construction. The LT-Weave is for motifs and patterns modification, and the LT-Design module is for textile design and visualization. All the digitized motifs and patterns are archived on our online repository for cultural preservation purpose, the online repository is a tool to store weave-drafts and for communication among researchers, weavers and cultural heritage experts. Experiment results of our research show that our approach closes the gap between traditional weaving and digital weave representations, fulfilling the aim of our project.

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Lathsamy Chidtavong
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Table of contents

Abstract (German) i

Abstract (English) iii

Acknowledgement v

Table of contents vii

List of figures xi

List of tables xv

Glossary of weaving terms xvii

Glossary of Lao terms xix

Chapter 1 Introduction 1
1.1 Overview of Traditional Lao Textile 1
1.2 Statement and Significance of the Problems 4
1.3 Motivations 5
1.4 Objectives 5
1.5 Scopes of the Research 6
1.6 Outline of Dissertation 6

Chapter 2 State of the Art 7
2.1 Diversity of Traditional Lao Textile 7
2.2 Religious and Socio Role of Traditional Lao Textile 9
2.2.1 Religious Role of Traditional Lao Textile 9
2.2.2 Socio Role of Traditional Lao Textile 11
2.3 Sources of Motifs and Hidden Meaning 12
2.4 Technical Weaving 15
2.4.1 Technical Weaving used in Laos 15
2.4.1.1 Technical Design and Drafting used in Laos 16
2.4.2 Technical Weaving on Electronic Loom 18
2.4.2.1 Technical Weaving on Hand Operated Loom 18
2.4.2.2 Digital Design and Digital Drafting 19
2.4.3 Weave Structures 20
2.5 Literature Reviews 21

Chapter 3 Analysis and Methodology 25
3.1 Field Trips to Laos 25
3.1.1 Excursion 1: August-September, 2012 25

3.1.2 Excursion 2: August-September, 2013 27
3.1.3 Excursion 3: August-September, 2014 28
3.1.4 Samples Collection 29
3.1.5 Summary on Field Trips 33
3.2 Pattern Analysis 33
3.2.1. Frieze Pattern Analysis 34
3.2.2 Wallpaper Pattern Analysis 36
3.2.3 Motif and Symmetry 39
3.2.4 Analysis Result 40
3.3 Mathematics and Algorithms for Digitizing 42
3.3.1 Digitizing Methods for Generating Motifs 43
3.3.1.1 Mathematics and Algorithms for Generating Lined Motifs 45
3.3.1.2 Symmetry Operations for Generating Single Motifs 46
3.3.1.3 Image Processing Techniques for Extracting Single Motifs 50
3.3.2 Mathematics and Algorithms for Generating Patterns 55
3.3.2.1 Generating Patterns by Symmetry Groups 55
3.3.2.2 Generating Patterns by a Simulation of Hand Floor-loom's Components 66
3.3.3 Digitizing Pattern-drafts and Weave-drafts 69
3.3.3.1 Separating Weft Set by Indexing 73
3.3.3.2 Adding Ground-weave to Pattern-drafts by Considering Weft's Index 75
3.3.3.3 Adding Ground-weave to Pattern-drafts without Considering Weft's Index 77
3.3.3.4 Removing Ground-weave from Weave-drafts 78

Chapter 4 Practical Implementation 79
4.1 LT-Tieup Module 80
4.2 LT-Weave Module 84
4.3 LT-Design Module 86
4.4 Workflow of Three Lao Textile (LT) Design Modules 88
4.5 Online Repository 89

Chapter 5 Experiment and Result 97
5.1 Experiment and Result on Digitizing 97
5.1.1 Workflow for Using Lao Textile (LT) Design Modules 97
5.1.2 Generating Lined Motifs 99
5.1.3 Generating Single Motifs 103
5.1.4 Extracting Motifs from Images 106
5.1.5 Generating Frieze Patterns 110
5.1.6 Generating Wallpaper Patterns in the First Category 115
5.1.7 Generating Wallpaper Patterns in the Second Category 119

5.1.8 Generating Wallpaper Patterns in the Third Category 122
5.1.9 Pattern Generation and Modification by the LT-Weave module..........125
5.1.10 Summary on Digitizing Experiment 127
5.2 Experiment and Result on Weaving 127
5.2.1 First Phase of Weaving with TC2 Loom 128
5.2.2 Second Phase of Weaving with TC2 Loom..131
5.2.3 Summary on Weaving Experiment...141

Chapter 6 Conclusion and Future Work 143
6.1 Conclusion 143
6.1.1 General Findings on Lao Textiles...143
6.1.2 Methodologies and Implementations..144
6.1.3 Digitizing and Weaving 145
6.2 Future Work 146

Bibliography 149

List of Figures

Figure No. Page

1.1 A photo of hand woven shawl 2
1.2 A composite motif: *Siho* with its filling motifs 2
1.3 An example of a wooden floor-loom and its manual weave-draft....................3
2.1 A shop of hand woven textile at night market in Luangphabang province....................8
2.2.a Shamanist banner shown in Lao textile museum in Vientiane capital 10
2.2.b Woven textile used to cover and protect Buddhist sacred scriptures shown in Lao textile museum in Vientiane capital....................10
2.3 A photo of Tai Daeng mosquito net shown in Phaengmai gallery, in Vientiane capital 12
2.4 A photo of Tai Daeng head cloth with *diamond Naga head* and *Siho* motifs shown in Phaengmai gallery, in Vientiane capital....................13
2.5 A photo of *Giant* motif designed on a blanket of Tai Daeng ethnic....................14
2.6 A collection of some master patterns from Nonesaad village in Vientiane capital 17
2.7 An example of weave-draft on supplementary heddles from Songpeur village in Vientiane capital 17
3.1 Types and number of collected samples shown in percentage 30
3.2 A collection of ethnic textiles and their corresponding percentage....................31
3.3 Locations of collected textiles and their corresponding percentage 32
3.4 Schematic illustrations of the seven symmetry groups of Frieze group 35
3.5 A diagram for Frieze Pattern classification based on seven symmetry group 35
3.6 A diagram for wallpaper pattern classification when the maximum order of the rotation equal to one....................37
3.7 Schematic illustrations of the wallpaper pattern generated by maximum order of the rotation equal to one....................37
3.8 A diagram for wallpaper pattern classification when the maximum order of the rotation equal to two....................38
3.9 Schematic illustrations of the wallpaper pattern generated by maximum order of the rotation equal to two 38
3.10 A diagram for wallpaper pattern classification when the maximum order of the rotation equal to four....................39
3.11 Schematic illustrations of the wallpaper pattern generated by maximum order of the rotation equal to four....................39
3.12 Schematic illustrations of the *cyclic* and *dihedral* groups for generating identity motifs 40

3.13 Symmetry groups and frequency found on the samples illustrated in percentage 41
3.14 A graphical feature of woven motif 43
3.15 A flowchart for extracting and digitizing motif by image processing techniques 51
3.16 A graphical representation of weave components 69
3.17 Example data sections on WIF file of figure 3.20 70
3.18 A graphical representation of inverse problem of WIF file 72
4.1 A *Use Case* diagram of the LT-Tieup module 80
4.2 A window of the LT-Tieup module with a popup menu 82
4.3 An example of a generated lined motif on the canvas 82
4.4 Examples of single motifs on the canvas 83
4.5 An example of generative Frieze pattern on the canvas with three repetitive motifs 84
4.6 A *Use Case* diagram of the LT-Weave module 85
4.7 A window of the LT-Weave module with a popup menu 86
4.8 A *Use Case* diagram of the LT-Design module 87
4.9 Workflow diagram of three Lao textile design modules 89
4.10 A *Use Case* diagram of the online repository 91
4.11 A page flow diagram of the online repository 92
4.12 A captured *Home* page of the online repository 93
4.13 A captured *Motif* page of the online repository 94
4.14 A captured *Pattern* page of the online repository 94
4.15 A captured *Textile* page of the online repository 95
4.16 A captured *Map* page of the online repository 95
4.17 A captured *Exhibit* page of the online repository 96
4.18 A captured *Register* page of the online repository 96
5.1 A workflow diagram for using Lao textile (LT) design modules 98
5.2 A photo of big motif, *diamond of Naga head* and flowers 100
5.3 A new created diamond motif (Size 33 x 38) 100
5.4 Unique segments and lined motifs in group 1 100
5.5 Unique segments and lined motifs in group 2 101
5.6 Unique segments and lined motifs in group 3 101
5.7 A result after adding line of *Naga head* 101
5.8 A result after adjusted line of *Naga head* 101
5.9 A first quarter of the desired motif with an empty diagonal space (size: 102 x 173) 102
5.10 A first quarter of the desired motif after filling corresponding lines to the empty space 102
5.11 A result of a first half's motif after operating its first quarter's segment (size: 203 x 173) 102
5.12 A complete desired motif after generating its second half segment (size 203 x 345) 103
5.13 Motifs of *cyclic* group 104

5.14 Motifs of *d1* and *d2* groups 105
5.15 A motif of *d4* group 106
5.16 A photo of cab motif with size (306 x 208) 108
5.17 A digital *cab* motif generated by the LT-Tieup module, (size: 81x65) 108
5.18 Extracting's result by filter sequence 1 109
5.19 Extracting's result by filter sequence 2 109
5.20 Extracting's result by filter sequence 3 110
5.21 Generating a Frieze pattern of *Hop* group 111
5.22 Generating a Frieze pattern of *Sidle* group 112
5.23 Generating a Frieze pattern of *Jump* group 113
5.24 A generative Frieze pattern of *Spinning Hop* group with three repetitive motifs 113
5.25 Generating a Frieze pattern of *Spinning Sidle* group 114
5.26 Generating a Frieze pattern of *Spinning Jump* group 115
5.27 Generating a wallpaper pattern of *cm_v* group 116
5.28 Generating a wallpaper pattern of *cm_h* group 117
5.29 A generated wallpaper pattern of *pm_h* group with two repetitive motifs in two directions 117
5.30 A generated two-directional pattern of *pm_v* group 118
5.31 Generating a wallpaper pattern of *pg_v* group 118
5.32 Generating a wallpaper pattern of *pg_v* group 119
5.33 A wallpaper pattern of *p1* group generated by the LT-Tieup module 119
5.34 A generated wallpaper pattern of *pmm* group with repetitive motifs in two directions 120
5.35 Generating a wallpaper pattern of *cmm* group 120
5.36 Generating a wallpaper pattern of *pgg* group 121
5.37 Generating a wallpaper pattern of *pmg_v* group 121
5.38 Generating a wallpaper pattern of *pmg_h* group 122
5.39 Generating a wallpaper pattern of *p2* group 122
5.40 Generating a wallpaper pattern of *p4* group 123
5.41 A digital wallpaper pattern of *p4m* group generated by the LT-Tieup module..124
5.42 A digital wallpaper pattern of *p4g* group generated by the LT-Tieup module..124
5.43 Design a pattern of *diamond flower* on the LT-Weave module........................126
5.44 A digital border pattern formed by *swan* and *diamond* patterns.......................128
5.45 A digital pattern of *diamond of Naga head* (size: … x …) 129
5.46 Weaving result of the first patterns' group on the TC2 loom 129
5.47 A digital weave-draft for weaving second section of the fabric 130
5.48 Weaving Result of the second patterns' group on the TC2 loom 131
5.49 A motif of *mating Naga* before adding plain weave..132
5.50 A motif of *mating Naga* after adding plain weave 132
5.51 A digital weave-draft of *mating Naga*'s pattern (Size: 660 x 87)....................132
5.52 Weaving result of the *mating Naga*'s pattern 132

5.53 A digital weave-draft of the *swan* pattern (Size: 660 x 47) 133
5.54 One-repeat *diamond* pattern with two weft-indexes, before adding plain weave 133
5.55 Weave simulation of one-repeat weave-draft of the *diamond* pattern with two weft indices, after adding plain weave..134
5.56 Weaving result of the *swan* and *diamond* patterns 135
5.57 A *mating Naga* motif with two assigned weft-indices (Size: 323 x 236).........136
5.58 A digital weave-draft of the *mating Naga* motif (Size: 660 x 471) 136
5.59 Weaving result of the weave-draft of *mating Naga*'s motif 137
5.60 A *Siho* motif with two assigned weft-indices 138
5.61 A digital weave-draft of the *Siho* motif (Size: 660 x 557)................................138
5.62 Weaving result of the weave-draft of *Siho* motif...139
5.63 A motif of *diamond's Naga head* with three assigned weft-indices (Size: 284 X 137)...140
5.64 Weave simulation of *diamond's Naga head* motif with three assigned weft-indices, after adding plain weave (Size: 284 X 458)...............................140
5.65 A weave-draft of the pattern of *diamond's Naga head* (Size: 660 x 458) 141
5.66 Weaving result of the weave draft of the pattern of *diamond's Naga head*..141

List of Tables

Table No. Page

3.1 Types and number of collected samples 29

3.2 Ethnic groups and number of collected samples...31

3.3 Textiles locations and number of collected samples...32

3.4 Group name, notation and short description of Frieze group 34

3.5 Group name, notation and short description of Wallpaper group..........................36

3.6 Identity motif and symmetry groups from textile samples 40

5.1 List of image processing techniques applied to the photos.................................107

5.2 Morphological operations results..108

Glossary of weaving terms

Backstrap loom	is a portable loom in which the warp is stretched between a stationary object and a belt the passes behind the weaver's back.
Draft	a diagram that represents a woven pattern. A draft for floor-loom will depict the threading, tie-up, treadling sequence and drawdown (pattern) of the cloth.
Drawdown	the main body of the draft to show structure of woven cloth.
Dobby loom	is a type of floor loom that controls the whole warp threads using a dobby head.
Filling	an individual yarn (also known as weft) which interlaces with a warp yarn at right angles in weaving fabric.
Floats	warp or weft threads that do not intersect. They are intentional "skips" that occur in woven cloth.
Floor-loom	a vertical loom which is a weaving tool to produce textiles by interlacing warp and filling yarns.
Heddle	the needle-like wires on a loom through which the warp yarns are drawn and raise and lower those threads during weaving.
Harness	a rectangular frame on a loom that holds the heddles through which the warp yarns pass. A loom's harnesses raise and lower the heddles in predetermined patterns so that the filling yarns can be threaded through the warp sheds to produce the desired weave.
Icon	the smallest pictorial unit of a design; the atoms of the motif.
Ikat	Malay-Indonesian words for a resist-dye process in which yarns are tied in selected areas to prevent penetration of dye and to form patterns when the yarn is woven
Lamms	a horizontal bar on the loom. The lamms connect the shafts to the treadles.
Loom	a weaving machine that produces textiles by interlacing warp and filling yarns.

Motif	integral group of one or many distinctive and recurring elements, forms, shapes, or figures. Motifs are the building blocks of a pattern.
Pattern	a design for decorating a textile composed of a number of elements (motifs) arranged in a regular or formal manner
Pick	refers to a single pass (or shot) of weft thread
Shaft	frame on the loom that holds the heddles; also know as harness.
Shed	opening between the upper and lower warp threads. The shuttle and weft threads pass through the shed
Shot	one pick, or pass of the weft thread.
Shuttle	the tool that holds the weft. Some types of shuttles include stick shuttles, boat shuttles, and end feed shuttles. (The device that carries the weft thread across the loom)
Tie-up	indicates which harness needs to be connected to which treadle. The tie-up is usually included in a weaving draft.
Treadle loom	is a type of floor loom where multiple heddles (shafts) were controlled by foot treadles- one for each heddle.
Treadles	pedals at the bottom of the loom that are attached to the lamms. Stepping on a treadle activates the shafts that are tied to that pedal.
Treadling	indicates what order to press down the treadles in order to lift the specific tie-up pattern. The treadling order is listed along the side of a draft.
Threading	is the way the warp threads are pulled through the heddles.
Warp	vertically aligned threads that attach to the front and back of the loom. A single thread is an end. (The lengthway threads in a loom)
Weft	the threads that pass through the shed from selvedge to selvedge. Weft threads aligned horizontally and are perpendicular to the warp. Weft threads are wound on to a shuttle. (The crossway threads in a loom, carried by the shuttle)
Weft face	the weft is dominant in the woven cloth. The warp is covered by the weft

Glossary of Lao terms

Dok	Flower, such as Dok Jik means Jik flower, and Dok Kab means Kab flower.
Hook	traditional floor-loom.
Nyak (Giant)	a mythical and spiritual creature its pattern on textile is considered as protector of people wearing it.
Khit	A weaving technique using a continuous supplementary weft in geometric forms
Khao	Heddles
Lai	Pattern
Siho	a mythical creature, animist believes this spirit creature will take shaman to spirit world during doing ritual.
Sinh	Lao traditional skirt which consists of three parts, head, body and hem.
Mat Mii	is a weaving technique, it is known as Ikat technique of creating patterns on woven fabric by tie-dyeing the yarn before weaving.
Naga or Nak	a mythical serpent lives under the river, animist believes it is ancestor's spirit and Buddhist believes it is Buddha's protector.
Pha being	a narrow shawl
Tam Chok	weaving technique whereby the warp yarns are picked out by hand to weave discontinuous or continuous supplement weft. *Chok* means 'pick' in Lao language.
Tam Mouk	a weaving technique using a supplementary warp yarn to design the pattern of textile
Mor Phorn	is an elder who has spent some time as a Buddhist monk. In Lao traditional ceremonies always performed by performed by Mor phorn, such as Baci ceremony.

Chapter 1

Introduction

This chapter will begin with an overview of characteristics of traditional Lao textile presenting significant problems, concerning the main motivation to do this research. After that, there will be a brief explanation of the motivation and three main objectives of the research respectively. Finally, the scopes and the outline of dissertation will be end part of this chapter.

1.1 Overview of Traditional Lao Textile

Laos consists of a variety of ethnic groups that are rich in traditions and cultures. Traditional Lao textiles are a women-craft heritage on clothes which are rich in religious motifs. The national costumes of Lao women are the main products of the textiles, traditional skirts called *Sihn* (tube skirt) with unique design styles as a symbol of Lao nationality. This cultural heritage is valuable property that deserves to be preserved, to be supported and to be passed on to the next generation. Due to the numerous ethnic groups that all have women's hand weaving skills at their disposal, despite their differences in religious beliefs, these traditions produce several mysterious motifs of identity on the textiles, which can be classified into many categories. The exact number of the motifs' categories with their hidden religious beliefs will be explained in chapter 2. The wealth in religious motifs is just one of several fields of traditional Lao textiles: the wonderful decoration of hierarchic motifs; the creativity of colorful embroideries and the descriptive creativity on pattern arrangement are other aspects that indicate the uniqueness of Lao textiles. The combinations of these attributes do not only make the textiles look beautiful and attractive to consumers, but they are also interesting to textile designers and textile researchers. The structure of textiles and their elements are a method to express the characteristics of the textile and the difficulties on weaving processes. They also show the differences between traditional Lao textiles and textiles from other countries.

Therefore, to visualize how complicated in design and decoration of traditional Lao textile figure 1.1 is a given example, a photo of a shawl. This exemplary textile consists of some striped patterns and two-directional patterns, which show a varying arrangement between small, medium and big patterns. There are various appearances of patterns and some of them are applied symmetry operations. Moreover, if we closely look at the motifs within the patterns, some motifs are asymmetric and some of them are symmetric, most of the designs are various symbols, a big motif is decorated by small motifs, a small motif is decorated by iconic geometries, and this hierarchic design represents an identity technique to form traditional Lao motifs. The details on how local weavers design patterns and make weave-drafts will be explained in chapter 2.

Figure 1.2 is another example to show a close look on a composite motif. It shows the big symbolic creature, called *Siho*, a dominant motif. It is a creature from a myth, a creature with a lion's body and an elephant's head. On one side, if we look at surrounding of the *Siho*, we would see that on along its trunk is decorated by lines of atomic icons, similar idea on along its tail also decorated by a group of reflected icon' lines. On the *Siho*'s back, there is a small *Siho*, which carries a *human* on its back. Furthermore, there are many small iconic motifs surrounding its body. If we look at the *Siho*'s body, we can see a *two-headed Naga* motif in *S* shape, motifs of *Naga* are the favorite motifs of Lao textiles. We could easily see that the style of its design is in the same fashion as the *Siho* motif. The *Naga*'s body is filled by atomic icons within the border of the body, and it is surrounded by other lines appearing along to the *Naga*'s body and some small motifs fill the rest of the empty areas. This example is only one of many Lao motif styles; practically a motif of the same creature could be displayed in different sizes or filled with different complementary motifs. This makes the design very flexible, giving the designer room for her creativity and imagination.

Figure 1.1
A photo of hand woven shawl.

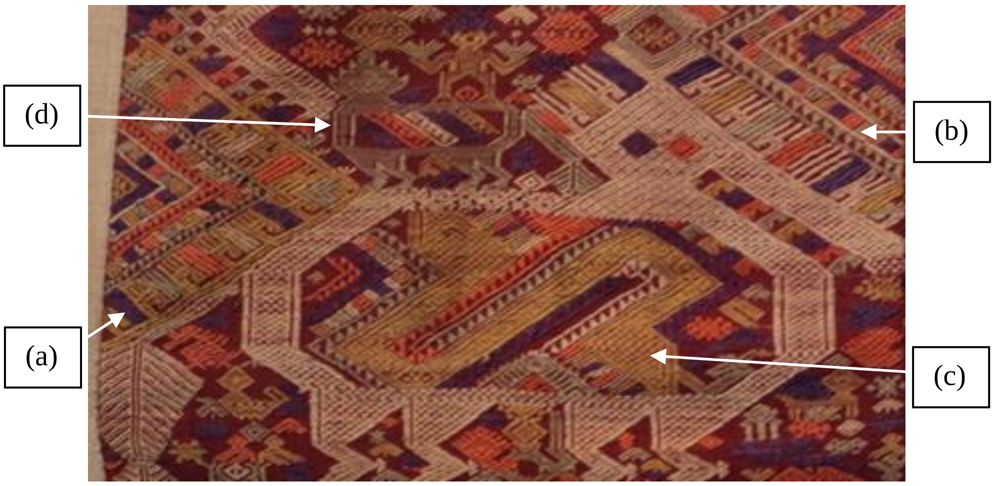


Figure. 1.2. A composite motif: *Siho* with its filling motifs.
a. and b. Examples of lines of atomic icons.
c. A *two-headed Naga* motif in *S* shape.
d. A *small Siho* motif carrying a *human*.

Because of their profound historical development, Lao women suffer from significant economic limitation and hand weaving is one heritage that Lao women can pass on to make living. Hand weaving textile is a tradition for self-sufficiency and provides a small income for women who have little education or who live in rural areas. Hence, it is not surprise to see people weave textile in every region of Laos, especially in rural areas, weaving textile is part of the people's livelihood. Nowadays, there are some textile manufactures in the capital and urban areas, but textile production still uses human labour. Most employed weavers are from rural areas; they have weaving skills but do not have the ability to run their own business. Actually, Lao weavers are skilful at weaving and natural dyeing. This strong ability makes weaving tradition still maintained by Lao women up to now. Unfortunately, weaving processes of Lao weavers are a very old tradition, which contains many technical limitations. Therefore, in this section we would like to introduce some technical problems concerning the hand weaving techniques used in Laos. We will give more details in the next chapter.

The first limitation is that the weavers have no design software and electronic tools for their support; a wooden floor loom (frame loom) is their main tool. A main weave technique is called "Tam Chok" represented a supplementary weft pattern weave technique where a master pattern and a weave-draft are set up on the loom by using a traditional method, tying supplementary heddles on the loom. The most risky of this weaving tradition is high percentage to lose weave-drafts.

Figure 1.3 is an example of traditional Lao floor loom, letter (a) shows a set of white threads called supplementary heddles where is a place to store a manual weave-draft, each row of the draft is separated by a tiny bamboo line, we marked by letter (b) on the figure. To weave a pattern on the loom, a weaver has to move a line of weave-draft, line by line in order to lift warp threads and to create a pattern row by row. The size of weave-draft in this example is approximately 80 lines; it means that to get one repeat pattern the weaver must move draft's line 80 times, but usually to weave ancient patterns need a weave-draft with more than 100 lines. Thus, making a weave-draft is a time consuming task, it needs skill and experience, if one line drops out from the heddles it takes time to fix it.

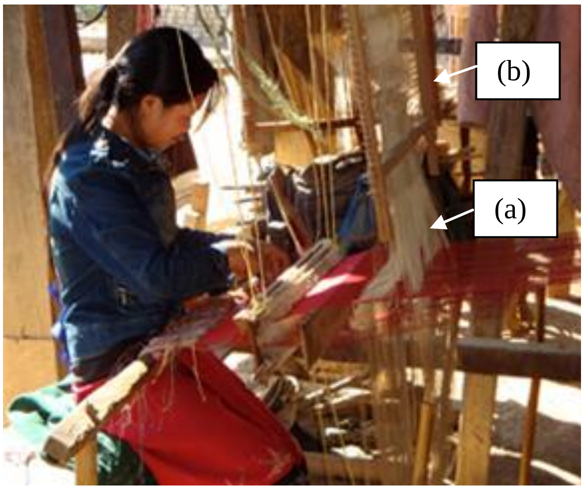


Figure 1.3
An example of a wooden floor-loom and its manual weave-draft

Another problem arises in this traditional technique; if the weaver wants to set up a new weave-draft there are only two options. The first option is to remove the old draft from the heddles, and then set up a new draft, by this way the weaver can weave a new pattern without waiting until the weaving reaches the end part of the warp threads. The second option is to use another set of heddles, if the weaver intends to reuse this current weave-draft, but the weaver has to wait until finishing the warp threads on the loom. These two choices are very inconvenient, because as mentioned before to set up a weave-draft on the floor-loom is very time consuming. Because of the technical problems above together with the complexity in motifs and patterns, the structure shows a lot of difficulties preserving this cultural heritage of Laos.

1.2 Statement and Significance of the Problems

Traditional Lao textiles have a central function concerning usability and the mentality of Lao people. The motifs and patterns on the textile reflect traditions, beliefs and livelihood of local people since ancient times. The creativity in motifs and pattern design creates a valuable cultural heritage to Lao people that seriously needs to be preserved and to be protected before they are depleted or taken by other countries that have similar cultures. Because traditional Lao textiles contain a variety of predominant motifs, there are few researches and books presenting studies about them in cultural context; they particularly focus on religious motifs. These small numbers of publications are a little help to preserve this culture when compared to numbers of negative effects that are increasing year by year. Since textiles are products that are used daily in Lao society, every year the number of textile production increases dramatically. The consumption is not only in local, but it is also in tourist industry. Because of economic factors, many of the traditional Lao textiles are transferred to sale in local tourist zones and to neighbouring countries that have a similar culture. These cause the traditional motifs to be edited and modified in order to make textiles look beautiful, colorful and attractive. Another impact to this heritage is a simulation of traditional Lao textiles by imported industrial textiles from neighbouring countries. They change the original appearance of motifs, and the traders concentrate only on the quantities of textile products. These trading processes gradually destroy original ancient motifs and pattern styles, and they make a high impact to Laos's cultural heritage. The technical limitations of local weavers with currently few supports in cultural preservation are still principle problems for Lao weavers, particularly for the cultural Lao heritage, waiting for suitable solutions.

On the other hand, computer aided weave design software and electronic looms are necessary tools for industrial textiles in many countries, especially in developed countries. In textile industry, weaving processes are controlled by electronic equipment; patterns and weave-drafts are digital files, which can directly be read by electronic looms. A lot of commercial CAD software has been introduced in the textile market, but they have been developed for specific types of looms, such as electronic Jacquard looms [25], different machines have different and sometimes individual software but this is only possible within textile industry. There are some commercial weave design software that have been developed for both hand looms and electronic looms called shaft looms or dobby looms [78]. However, shaft looms are different from floor looms that are used in Laos and actually digital weave-drafts are created based on the type of loom used. Therefore, in scientific terms weave-drafts are a key to connect traditional Lao weaving techniques and modern weaving technologies; this connection is a first step to introducing a new technical tool to a society of hand weaving textile in Laos, it will help to improve the weaving process of local weavers. Moreover, scientific methods for data repository are widely studied among computer scientists; a suitable database, requirement data and data structure in a database are important points in repository technique.

From this point of view, they have inspired us to do this research, which is interdisciplinary research between computer science and digital textile design and weaving. The motivations and objectives of this research are going to be explained in following section.

1.3 Motivations

Regarding the technical limitations on Lao traditional weaving techniques and the necessity in cultural preservation, we, as computer scientists, would like to work on this cultural topic within a scientific context, connecting old weaving tradition in Laos with the modern world of weaving technology. The developed tools in our research aim to contribute to traditional hand weaving or local weavers in particular. Furthermore, the study and the developed tools in our research are set to support and to preserve Lao national and cultural heritage.

1.4 Objectives

This research aims to treat three main objectives: firstly, to construct a digital data model of traditional Lao motifs and patterns. The second goal would be, to develop a software tool for Lao textile designers or Lao textile weavers. The constructed digital data models were stored as built-in motifs, patterns in the software. The final objective is to create an online database for digital archiving.

Concerning traditionally woven Lao textiles with a focus on cultural preservation, we have developed our interdisciplinary research to investigate scientific methods, which are keys to fill the gap between the old weaving technique and a modern weaving technology. Three main design modules were created to form the design software Lao Textile (LT). The LT-TieUp module aims to design motifs and patterns, the LT-Weave is provided to modify patterns, while the last module LT-Design is used to design and visualize a complete textile, preparing the weaving of textile on a loom. To archive our results we created an on-line repository digital archive, which is used not only for storing traditional motifs and patterns, but also as a tool for communication among weavers, researchers and cultural heritage experts. The software tool developed in our project and the online database play an important role in supporting the weave-drafts (digital Lao motifs and patterns) for weaving and archiving. In our research we investigated different scientific algorithms for generating weave-drafts, leading to international standard formats which are understandable and usable for both hand-weavers and weaving machines.

1.5 Scopes of the research

- This research investigates only motifs and patterns that apply supplementary weft-faced patterning "Tam Chok", which is a main technique used in Laos
- All the algorithms are developed to support and contribute to hand woven textiles in Laos-The developed design modules are focused on designing and drafting for traditional Lao textile only
- Weave-drafts are created in two standard formats, WIF (weaving information file) and image file formats, which are commonly used for modern weaving technique
- The online database provides information of traditional Lao textile and all stored weave-drafts are digital weave-drafts of traditional motifs and patterns of traditional Lao textile only.

1.6 Outline of Dissertation

This dissertation is divided into six chapters. Chapter1 is a current chapter where we begin by an overview of characteristics of traditional Lao textile. After that, the overall problems are pointed out and then followed by the clear explanation of the solutions we aimed at, according to the defined objectives and motivation.

Chapter 2 goes into the more technical details of traditional Lao textiles, and then introduces some observed modern weaving technology. The literature review will be the final part of the chapter. It will depict many cultural studies, researches on science of design and researches on weave technology; finally we present the difference of our research to other research.

In chapter 3 three field trips for data collection and analysis results on traditional Lao textile will be the first part of the chapter, after that mathematical concept of symmetry groups for generating motifs, Frieze patterns and wallpaper patterns will be introduced. Followed by algorithms, methodologies for digitizing and the algorithms for weave functions will be last part of discussion in this chapter.

The implementation of all mathematical equations and algorithms that are described in chapter 3 will be explained in chapter 4. This chapter will introduce three design modules that are aimed to support particular design tasks and the last part of the implementation will introduce a technical tool to develop an online repository for digital archiving.

The investigated methodologies and the developed tools are tested together in chapter 5; many experiments are explained, the experiment results in each case are presented and discussed step by step. The experiment starts from testing the design modules to digitize motifs, patterns and weave-drafts. After that, we test digital weave-drafts with electronic looms; the TC2 loom is selected for this weaving experiment.

Finally, the overall conclusions and some possible expansions of this research are explained in chapter 6. The remaining tasks of this research will be explained and the suggestions of some possible ways are pointed out in order to enhance this cultural study in the future.

Chapter 2

State of the Art

This chapter will start from briefly introduce the background of traditional Lao woven textile, and then follows by the role of the textile to religions and society in Laos. After that, we will bring out the relations between textiles and religion beliefs which become the sources of a variety of mysterious and attractive motifs. Moreover, the introduction of traditional weaving techniques and modern weaving techniques will be demonstrated before going to point out the literature reviews in cultural context and scientific context. At the end of the chapter the different methodologies used in our research are identified by comparing to previous literatures.

2.1 Diversity of Traditional Lao Textile

The government of Lao People's Democratic Republic (Lao PDR) categorized Laotian citizen into three main groups, Lao Loum, Lao Soung and Lao Theung [31] where Lao Tai ethnic group is a biggest subgroup that belongs to Lao Loum. Lao Tai people are well known as skillful hand-weavers, the appearances of Lao Tai textiles, motifs and patterns are various from region to region [13]. Traditional weave techniques invented by Lao Tai are widely used and they become main used techniques among Lao weavers, such as *"Mat Mii"* (ikat) and *"Tam Chok"* which is a supplementary weft pattern weave technique. Lao Tai subgroup consists of many ethnics and hand-weaving is a craft tradition of them. Women in every ethnic group can weave and invent their own weave techniques. The study from [39] described some characteristics of Lao woven fabrics. The names and usage of traditional skirts in each ethnic were listed; the samples of textiles were collected from north to south. This study revealed that the appearances of motifs and patterns were various, especially on Lao Loum textiles. A variety of traditional textiles were also presented by Lao women's union in 1995 [13], 131 items totally collected which were classified into 3 groups, clothing, items for daily use and items used in ritual activities. Moreover, there are many types of traditional skirts were recorded in the book "Sinh and Lao women" [79]. The study of this research focus on traditional textiles that produced by Lao Tai people. We investigate the ethnic textile; the observations on the textiles are based on weave techniques and characteristics of the textiles in each ethnic group. In the following section, we will start to explain ethnic textiles of Lao Tai from the north to the south of Laos.

Tai Dam and Tai Daeng ethnics mainly live in Huaphanh province and some of them live in Xieng Khuang province, people of these two ethnics are well-known as skillful weavers. They are shamanists who believe in spirit world or life after death. Shamanists textiles are not only for daily use, but some textiles are for rituals and ceremonies. Varieties of mysterious motifs are from these two ethnics, the most symbolic motifs on their textiles are inspired and imagined from belief of shamanism.

The most Tai Phoaun ethnic lives in Xieng Khuang province which is neighboring province of Huaphanh. Tai Phoaun people are Buddhists; motifs on their textiles are copied from Buddhism epics. Actually the strange creatures of the shamanic tradition reinterpreted well as the hybrid heavenly beings in the Buddhist mythical forest of Himmaphan. Hence, these two great belief systems expressed themselves most profusely in their textiles [61][59]. The most Tai Lue people live in Luang Phabang and Oudomxay provinces; they have long reputation in weaving skill, in an era of kingdom Tai Lue had responsibility to weave fabrics for royal family, this reputation was explained by P. V. Esterik [63] who is a professor of anthropology. Because the geography in north of Laos are mountainous and surrounded by beautiful nature, forest and rivers. The combination of these attributes together with the complex belief in spirit world make textiles in this area more complicated, wonderful and attractive than textiles from other areas. As a result, the traditional textiles in this area are high demands for tourist industry and textile collectors. For instance, the city of Luang Phabang province has been promoted as world heritage site 1995; it is a central market of crafts for tourist industry. Figure 2.1 shows an example textile shop in night market in Luang phabang. The reputation of traditional textiles in this area is described in many books which were written by foreign authors who fall in love to the charm of Lao textiles [77] [50] [59] [60].

Figure 2.1
A shop of hand woven textile at night market in Luang phabang

Phou Tai is another big subgroup of Lao Tai who live in middle part of Laos, mostly found in Savannakhet, Khammoaun and Bolikhamxay provinces. Phou Tai invented ikat, local called "*Matt Mii*" as their main weave technique. *Tam Chok* is normally used only for making skirt hem and some stripe patterns. The historical background of Phou Tai, their weaving skill and their textile products were explained by Linda S. McIntosh [44]. Furthermore, the publication from [7] is another reference to show weaving skill of Phou Tai group even though they were migrated to a neighbor country since war in many years, but they still keep using their old style of weaving tradition. Normally, motifs created by Lao Tai who live in southern Laos particularly in Champasak province are simple the most of them are inspired from nature. In general, motifs made by Tai Phoun and Lao Tai people in southern Laos are not complicated, the source of motifs are from nature and Buddhist worship Items. Since hand woven textiles are main daily used clothes, Vientiane Capital is another traditional textile market which is central market, textile items from north to south are transferred to this place. Therefore, motifs and patterns in this area are various, and it is difficult to distinguish their original ethnic group, some textiles are decorated with the combination of motifs from many regions and from many ethnic groups.

2.2 Religious and Socio Role of Traditional Lao Textile

2.2.1 Religious Role of Traditional Lao Textile

Traditional textiles in Lao PDR play important role in religions and society, particularly in special and holy events in life such as wedding and celebration [13]. In Laos, the most rituals and festivals are related to religions and the yearly rice farming cycle. The timing festivals are calculated according to Buddhist lunar calendar. The strong belief of shamanism and Buddhism are main factors that influence the role of textile to religions. The shamanists believe in spirits, the local guardian spirit of each village is appealed to at the beginning of the agricultural year for successful crops. These spirits should also be informed of major changes in person’s life: sickness, a move, a marriage. While Theravada Buddhism regards Buddha as a great teacher, Buddhists believe that a person’s karma is the balance between good and bad deeds. It will affect this life and future reincarnations. Therefore, “Merit is a key concept of Buddhists” [66], merit is accrued through good action, or good “karma,” over a series of many births. The belief of these two religions influence different kind of textiles produced for specific purpose, for example, healing clothes and funeral clothes of shamanism, ceremony clothes and scriptures’ cover of Buddhism, banners for making merit of both religions. To express the important role of these cultural textiles, we will explain the concept of their usage in each occasion as follows:

Shamanic healing clothes: healing clothes are used in healing ceremonies, and are also used in ceremony to foster a healthy future for the village or crops. A particular explanation of shamanic healing clothes was explained by P. Cheesman in [58]. The textiles may be worn by a healer, or an ill person. Each ethnic group, sub-group has unique styles of weaving and ritual to express their spiritual lives and needs. The shamanists see the world through the eyes of their ancestors. The shamans who travel to the spirit world in trance and communicate with the ancestors, the ancestors give advice on healing methods through the shaman as well as explain the reasons for natural disasters or sickness due to menacing strangers' spirits or ancestors that are angry or dissatisfied. The ritual tools and symbols of shaman’s journey are decorated on the textiles. The shaman is formed as a human motif on the textiles; in some textiles are formed shamans as human standing on a *Naga boat* or standing on the back of mysterious animals. The symbolism of the textiles are powerful tools of shaman and decorative bands patterns representing a ladder is a pathway to chase out evil spirits and the souls of sick persons to return to their body.

Funeral clothes and coffin covers: The body of the departed is dressed in the finest new clothes the family can afford; and several sets of clothing are placed in the coffin with the corpse as it lies in state. It is believed that by offering textiles make the deceased more comfortable in their next life. The mythical motifs on the textile are protector to protect the dead during their journey to the spirit world.

Banners: banners in the shamanist tradition were woven by the daughter in law for funeral ceremonies of her husband’s family **[**61**]**. During the ceremony, the banners are displayed outside the house of the deceased person and then taken to the entrance of the funeral ground to warn passersby not to enter the sacred space. Buddhist banners were decorated with symbols of palaces and mythical creatures of heaven and represent a ladder by which the soul of the dead can pass between earth and heaven. Buddhist banners are able hung on poles topped with carvings of birds which are believed to carry the soul of the dead to heaven. [66] Banners concerns of afterlife and final journey to heaven often influence on the design. Merit is a key concept of Buddhists and is the main purpose for the donation of banners. Hand woven banners are given to the Buddhist monastery or are erected at the cemetery as a memorial. Furthermore, cotton shawls are woven to cover and protect Buddhist sacred

Figure 2.2.a
Shamanist banner showed in Lao textile museum in Vientiane capital

Figure 2.2.b
Woven textile used to cover and protect Buddhist sacred scriptures shown in Lao textile museum in Vientiane capital

scriptures, utensils of monks or even sacred Buddha statues. Figure 2.2.a on the left side showed an example of shamanist banner and Figure 2.2.b on the right side showed an example of cotton fabric covered a Buddhist sacred scripture.

Buddhist's ceremony clothes: Buddhist textiles are also special importance in Siu Khwan (calling of the life essence) ceremonies, such as Siu Khwan ceremony for new born baby, Siu Khwan ceremony after recover from illness and so on [33][34]. For example, the traditional Lao wedding is one of the most significant ceremonies in peoples' lives, requires fine and elaborate costumes and clothes for bride, groom and the "master of the ceremony" ("Mor Phorn"). On Buddhist ceremonial occasions, men often wear a shoulder cloth or sash with simple patterns. Women wear cotton or silk skirts and shoulder cloths which are decorated with religious motifs.

2.2.2 Socio Role of Traditional Lao Textile

The government of Lao P.D.R indicated Lao Luom's costumes to be a national costume of Laos, while the national dress of women consists of a traditional tube skirt called "*Sihn*", a blouse and a shawl or a sash (a shoulder cloth). As a result, *Sinh* is an official dress, women wear *Sinh* during work in the office or when they go to government places, it is impolite and unacceptable for wearing pant, short pant or short skirt in government places and in formal occasions. Therefore, *Sinh* and shawl are main used fabrics among society. This clearly shows that traditional Lao textiles play an important role to society and to being Lao nationality. The role of textiles implies the role of Lao women, from the past to present, women continue to be weavers of all kinds of traditional textiles, and they are producers and consumers. Since ancient time, women have been responsible to produce textiles for household items in family, such as: skirt, shawl, blanket, pillow case, curtain and so on. [13] obviously gave examples on how textiles are used from first born baby to daily life, in official and in ceremonial occasions. The collection of many hand woven households' items can be seen in Lao textile museum and in Phaengmai gallery, such as blanket, curtain and mosquito-net of Tai Dam and Tai Daeng ethnics. The typical Lao Tai house consists of a wide communal sleeping loom for all members of the family, a kitchen, and a hall, so thick curtains are used to separate areas. The black mosquito-net in is one of the main household items for newlyweds. The study about role of Lao textiles to people in each ethnic group was also studied and explained in detail by K. Ketavong in [39]. Figure 2.3 is a photo of Tai Daeng mosquito-net shown in Phaengmai gallery, in Vientiane capital.

From time to time, the role of textiles to Lao people has never changed, all of Lao women still proud to wear their traditional costume. The requirement of textiles is increasing yearly not only from local market, but it is also from tourist market. Weaving textile is not only for religious ritual and ceremony anymore, nowadays a lot of contemporary textiles are produced for purchase. The decoration on the textiles focuses on only beauty purpose; the ancient motifs are modified without considering its appearance and its hidden meaning. As a result, many scholars and textile researchers studied the trend of traditional Lao textiles; they also warned Lao government to take action for protection and promotion this cultural heritage. Cheeman [65] analyzed the physical properties that reveal change between the tradition and contemporary Lao textiles in 2004. G. Candominas [28] suggested that from the excellent reputation of the local crafts and the close co-operation customary between the minority populations and the Lao Loum on this highly inspiring site, the Lao Government should be eager to go ahead with the safeguarding of the culture of present-day minority and majority populations. P. V. Esterik [63] commented on Lao P.D.R that is a country rich in culture, particularly in the diversity of ethnic groups and cultural traditions, the country is especially rich in traditional woven textiles. If the production of traditional textile considers the historical and cultural context of textile, Lao PDR would be able to increase economy to local people and be able to preserve culture simultaneously. The local textile researchers also pointed out the importance of textiles and the need more researches on them in order to preserve, to contribute and to pass on the knowledge to younger generations for the maintenance and prosperity of Lao culture. D. Bounyavong [79] is a writer and a researcher on Lao textiles giving suggestion that textile productions should deserve every form of support and promotion, whereas a new generation of weavers, who develop or adapt old motifs to match the modern style, they should never forget the significant contributions of all Lao weavers of various ethnic groups.

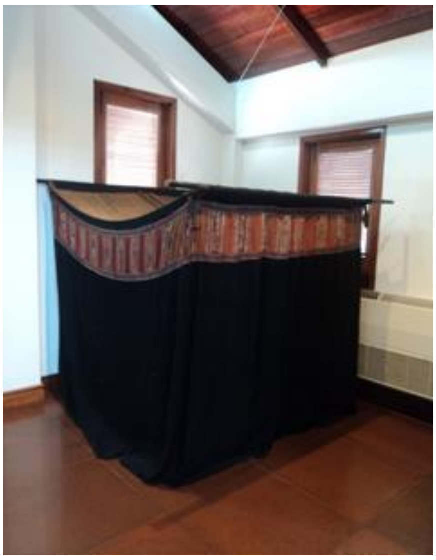


Figure 2.3
A photo of Tai Daeng mosquito net shown in Phaengmai gallery, in Vientiane capital

2.3 Sources of Motifs and Hidden Meaning

To give an idea and to understand the deep meaning of motifs on Lao crafted textiles, it is important to understand religious and philosophical background of the people. Traditional Lao Textiles carry symbolic meaning and are woven for several purposes. Environments, religious beliefs, folktales and epics are main sources of motifs. For example, plants from agriculture and nature, wild and home animals, and natural phenomena, such as, lightning and water flow are copied into textiles. A book" Legends in the Weaving" [14] showed some predominant ancient motifs with the description of their belonging ethnic group and technique used. The motifs on the book were classified into three groups: the first was a group of beneath water mythical animals; the second was a group of mythical animals on earth and the last group was a group of plants. Actually, the classification of motifs is various among books, it depends on the interest of authors, some of variable books are [77][60][79] and [61].

However, in this research we investigate ancient and traditional motifs, we classify them based on types of mythical creatures, plants and animals, namely: *Naga*, *Siho*, *Giant*, *Bird* while plants, small animals and other symbols are classified in the same group, totally we have 5 groups of the motifs. Meaning of the motifs is regarded agriculture and religious rituals, ceremonies. We will explain their meaning from group to group as follows:

Group of *Naga* motif: an ancestor spirit of shamanism and Buddha protector of Buddhism

Naga is a mythological water serpent with natural power, local people called **"**Nguek", "Luang" and "Pha ya nak". *Naga* is symbolized and characterized significantly for Lao society and culture, the symbol of *Naga* patterns in all Lao textiles shows the movement of *Naga*. In shamanist belief, *Naga* is an ancestor spirit whilst in Buddhist belief, *Naga* is a Buddha's protector. From these two belief systems, *Naga* figures on clothes are interpreted as wearers' protectors from dangers. As a result, a variety of imaginations of *Naga*'s action are created and named by weavers, such as: *sleeping Naga*, *awake Naga*, *mating Naga*, *pregnant Naga* and so on. The research from Asia Research Center of National University of Laos (ARC-NUOL) [2] revealed 96 types of *Naga* motif. The motifs were separated into three groups based on *Naga*'s appearance. The *Naga* motifs designed with *Dok Kab* (hook flower) to form a zigzag line or a diamond are in group one. The motifs of whole body of *Naga* are in group two, and lastly a group of *Naga's herd*. In coffin cover of shamanism is often embroidered *Naga* patterns; because *Naga* will protect the death during go to spirit world. In ancient time, people often used fabric with patterns of *Naga's herd* to wrap their treasures. Figure 2.4 is an example of *diamond Naga head* that belongs to the group of *Naga's herd*, two end part of the cloth were also decorated by *Siho* motif which is common used motif in Lao textiles.

Figure 2.4

A photo of Tai Daeng head cloth with *diamond Naga head* and *Siho* motifs shown in Phaengmai gallery, in Vientiane capital

Group of *Siho* motif: *Siho* is a mythological creature from epics; it is a creature that mixed from two animals, elephant and lion. According to local epics, *Siho*'s head is elephant's head and *Siho*'s body is lion's body. *Siho* is a powerful creature and has supernatural power. As a result, *Siho* motif is the second commonly used on the textiles apart from *Naga* motif, especially in shamanist textiles. The motif of *Siho* is considered as a spiritual animal of shaman that can take shaman to go to and to come back from spirit world. Due to *Siho* and *Naga* are the most powerful mythological creatures on the textile [77], they are often decorated together on the textile, *Naga* is often designed as trunk of *Siho* and inside *Siho*'s belly, this design is called *Siho pregnant Naga*. An example of *Siho* motif was already shown in figure1.2 in previous chapter.

Group of *Giant* motif: *Giant* is a mythical creature from epics and Buddhist myths**,** its figure becomes a protector when embedded in the textile [20], local people called *"Nyak"***.** According to the epics and myths, there are good and bad *Nyaks*, the good *Nyaks* are considered as Buddha protectors. Therefore, in every Buddhist temple we will see many sculptures of *Nyak* stand beside both sides of a main gate of the temple and in any area inside the temple. *Nyak* or *Giant* motifs woven on textile are also considered as guardians. For example: on door-curtain and window, *Nyak* will guard people in the house from any evil spirit outside. The *Nyak* motif on baby carried clothes, head clothes are other example used of *Nyak* motif. In ancient time, travelling from one village to another village took several days, at night was necessary to stay in the forest. A *Nyak* motif on their textile became a mental tool to feel safe from the dark atmosphere.

Figure 2.5
A photo of *Giant* motif designed on a blanket of Tai Daeng ethnic

Group of *Bird* motif: *Bird* motifs are part of various antique and contemporary textiles. In this group we collected all *Bird* motifs from our sample textiles and from materials of references. The motifs are separated into general poultry and mythical bird. For instance, *Hong* motif means a *swan* is a legendary creature that represents prosperity, elegance, lives in the forest and can fly up to heaven. *Nok Hadsading* is a bird-elephant motif from Himaphan forest in Buddhist myth. It is a mythical creature which its head is elephant's head and its body is bird's body.

Group of Plants, Animals and other symbols: symbols of plants and animals on textiles mean wealth of agriculture. For example: Crab motifs symbolize a rich harvest. A motif of *Khon Thani* (gibbon-person) or *frog-man* is a symbol of rain and reproduction. However, the *Khon Thani* on shamanist textile is represented as ancestor spirit who is a guardian and protects people in a family form evil spirits. A motif of diamond or rhombus shape is another powerful protective symbol; it is considered as a scared eye or a third eye of shaman in shaman's head cloth. The diamond motif is often designed with flower, such as diamond of *Dok Kab* called *Khom Kab,* diamond of hooks called *Khom Khoud* and so on.

From the explanation above shows the plenty of mythical motifs and religious beliefs. Because the most motifs are hidden positive and good meanings, this is a reason why there are many various motifs designed on one textile. On the most complicated and beautiful textiles are often combined four powerful motifs: *Naga*, *Siho*, *Giant* and *Diamond* motifs.

2.4 Technical Weaving

In order to provide background of technical weaving, in this section we will introduce all related terms of weaving, such as looms which are weaving tools, weave techniques and drafting techniques. We will begin the section with introduction of looms and weave techniques used in Laos, after that background of observed electronic looms will be introduced. Due to looms are main tools to produce fabrics and the variety of fabric's structures depends on type of loom, a different loom will produce different characteristics in fabrics. So, the looms in various types are developed and available in textiles markets. In order to compare and to connect technical weaving used in Laos to other common and modern technical weaving, we consider modern electronic looms, the looms are semi-automatic or hand operated and work similar to Lao floor-loom, their technical weaving will be explained in section 2.4.2. Drafting technique is another important point that is always considered among developers, because drafting is a first step of weaving without drafts weavers do not know what to weave. Therefore, we will introduce standard file format for digital design and drafting at the end of the section.

2.4.1 Technical Weaving used in Laos

Hand weaving system in Laos is an old weaving tradition that uses only two types of simple wooden looms, a floor loom and a backstrap loom. The floor loom is the most widely used by Lao Tai people who are formed majority groups, the backstrap loom is only used by minority people who live in southern Laos. Actually, type of looms is able to indicate numbers of possible weave techniques for the loom while a loom and weave techniques are able to indicate an appearance of a pattern. As a result, weave techniques used in Lao Tai group on the floor loom are *Tam Chok*, *Tam Mouk*, *Mat*

Mii and tapestry weave. *Tam Chok* is a mainly and intensively used technique, it is a compound weave between plain weave and a supplementary weft pattern weave, the plain weave is woven as ground fabric where the pattern weave uses continuous or discontinuous supplementary weft to produce patterns. *Tam Mouk* is a warp-face patterning technique; it is similar to *Tam Chok*. It is a compound weave between plain weave and a supplementary warp-face pattern weave. It uses two set of warp threads, the first set is a set of main warp threads that are used for plain weaving. Another set is a set of supplementary warp threads for warp-face patterning. *Mat Mii* in English called "ikat", it is a tie-dyed patterning weave, its patterns are predesigned by tying on weft threads, after that the threads are natural dyed by traditional technique. The last technique is a tapestry weave, its patterns by using different colors of weft threads interlace with warp threads to create patterns. These weave techniques are sometimes applied in one fabric, especially in skirts and in shawls. For example, *Mat Mii* and *Tam Chok* are often applied for weaving a skirt's body while a skirt's hem is woven by *Tam Chok*. The explanation and example textiles with their combination weave techniques can be found in [13]. The investigated motifs and patterns in this research are mainly from *Tam Chok*, because this technique provides designers to enable to make complicated patterns. Woven patterns from *Tam Mouk* and from weaving on the backstrap loom are simple patterns, so they are not considered in this research we restrict only on traditional hand floor-loom, because the hand floor-loom is a main tool used in Laos. In the following section we are going to introduce design techniques and drafting implemented among Lao weavers.

2.4.1.1 Technical Design and Drafting used in Laos

Stripe patterns and two directional patterns are standard pattern style that can find in any kind of cultural art. The same as another craft-art, Traditional Lao textiles are also implemented these standard design techniques on the pattern decoration task. The traditions of pattern designs on Traditional Lao textiles have been kept in ancient styles, the combination of stripe patterns and two directional patterns on the textiles can be seen on any kind of Lao textiles, especially on skirts and shawls. In general, stripe patterns are designed as complementary patterns; their designs are various from small band to large band, in animist textiles the arrangement of stripe patterns on two end part of a shawl means a ladder to come in and to go out of spirits during ritual practices. The two directional patterns are often designed as dominant patterns; the patterns are often decorated on the middle part of the textiles. Mathematical basis on pattern generation and their associated symmetry groups will be explained in chapter 3. Figure 2.6 shows some master patterns from a weaver's collection in Nonesaad village in Vientiane Capital, Laos.

Since the complexity of motif's structure and the complexity in pattern's composition, weave-drafts have at least 50 lines; particularly weave-drafts for the most complicated patterns have nearly 800 lines. Furthermore, Lao weavers store their weave-drafts in two traditional ways for reused purpose, especially for the most

Figure. 2.6
A collection of some master patterns from Nonesaad village in Vientiane capital

Figure. 2.7
An example of weave-draft on supplementary heddles from Songpeur village in Vientiane capital

complicated patterns. The first common way is to store weave-drafts in a set of heddles (supplementary heddles), before finishing warp threads from a loom, weavers weave a master pattern and then leave it with its drafts on heddles, the master pattern and heddles are tied together by warp threads. When a weave-draft is needed again, the supplementary heddles are re-installed on the loom by connecting warp threads on the heddles to a new set of warp threads on the loom. Weavers can see an example pattern of the weave-draft from the master pattern and they can follow the weave-draft to weave new fabric of this pattern. Another way for reused patterns is collecting master patterns; normally this method is for keeping less complicated patterns, the master patterns are served as weave-drafts, it means that the weave-drafts are removed from heddles; weavers keep only a piece of master patterns when the patterns are needed to weave, weavers have to make a weave-draft on heddles by following the master pattern, from this method a new pattern design can be created by using one master pattern or by combining motifs and patterns from variant master pieces. In addition, the designs of patterns on the contemporary textiles today are still follow these techniques.

2.4.2 Technical Weaving on Electronic Loom

The observed electronic looms are selected by according to their similarity to the traditional floor-looms used in Laos. The purpose of the observation is to compare and to create a technical link between Lao floor-looms and the electronic looms, mechanical term of the looms is out of our observation, and we focus only on technical weaving of the looms. The observation concentrates on how the looms operate weave-draft and which part of weaving process the loom assists weavers. We considered two semi-automatic looms or hand operated looms, namely the Dobby loom and the TC2 (TC2: Thread Controller Number 2) looms. General technical information of the looms will be introduced first, and then follow by detail of the dobby loom and TC2 loom.

2.4.2.1 Technical Weaving on Hand Operated Loom

The hand operated loom works similar fashion to a standard hand floor loom with the weaver throwing the shuttle, advancing the warp and beating the cloth. However during weaving instead of deciding which shafts or how many warps to raise each pick, the weaver leaves this task to the loom by providing a digital weave-draft. The digital weave-draft provide as loom’s instruction to determines which shaft to lift each pick, and then the loom opens a shed for that current pick. Techniques to lift warps in each hand operated loom are different. The basic loom’s equipment is going to present below before moving to explain technical term of each loom.

- **The warp beam:** this is the roller on which the warp ends are wound for weaving. It is also known as warp roll.
- **Shaft/Harness:** is the frame of the loom that holds the warp threads. These shafts can be moved up or down by treadles to allow the weft to cross through and create the desired pattern. The more the number of harness, the more patterns we can create. The number of harnesses can is in between two and thirty two.
- **Heddle:** heddles are made of wire or cord. These hang from the shaft of a loom and have an eye in the center. The warp is threaded through the eye of the heddle and there are as many heddles as there are warp threads. Heddles are crucial to the weaving process because it is these heddles that are raised or lowered when the shaft is moved causing the warp to be moved for interlacing with the weft to create the pattern. The distribution of the heddles is determined by the pattern to be woven.
- **Shuttle:** this is a tool that holds the yarn and carries it across the warps to create the weave.

- **Reed:** the reed is a comb-like frame with vertical slits that secures the weft in place as it is woven in. It helps to keep the warp untangled and guides the shuttle across the loom.

Hand operated Dobby loom

A Dobby loom is a type of floor-loom that controls all the warp threads using a device called a dobby. Every warp thread on the loom is attached to a single shaft using a device called a heddle. A shaft is sometimes known as a harness. Each shaft controls a set of threads. Raising or lowering several shafts at the same time gives a huge variety of possible sheds (gaps) through which the shuttle containing the weft thread can be thrown. A computer-assisted dobby loom uses a set of electric devices called solenoids to select the shafts. Activation of these solenoids is under the control of a computer program where the selected shafts are raised or lowered by a dobby pedals. For more detail of the Dobby loom see [78].

Thread Controller TC1, TC2 looms

Digital Weaving Norway presents the Thread Controller Number1 (TC1) and Number 2 (TC2) loom which are the ultimate design tools for weavers. The loom is ideal for designers working freelance or in mill design studios, for educational institutions, for small scale production in hand weaving, for artists, etc. The TC1 and TC2 looms allow a designer to have complete control over thread in the warp, and every row of the weft, allow a non-repeating design to cover an entire piece and allow the weaver to use a wide range of yarn sizes and fiber types. Each yarn in the warp and the weft is still placed by hand. One can easily stop and start the loom control to experiment with yarn, color, and weave combinations, before choosing the final weave plan. For more detail of the Dobby loom explain in [83].

2.4.2.2 Digital Design and Digital Drafting

The purpose of drafting is to find out what a pattern will look like before going to all the work of making a warp and threading the loom. The drafts are planned in various ways according to tradition or country of origin and type of loom. In Europe and United Stated of America (USA), a treadle loom is widely used; it is a type of floor-loom. As a result, the most found drafting techniques were based on the structure of treadle loom, such as weave-drafts provided by [10] and [37]. The draft of treadle loom indicates the threading of the warp, the tie-up which is a manner to tie the shafts/harnesses to the treadles, and the treadling sequence. Drafting on paper is the same method as drafting on the computer, except that the computer does it much faster with a greater degree of accuracy than the human process of producing a pattern on paper. The draft can then be printed out, so that it can be taken to the loom for handy reference when threading or treadling.

The standard digital weave-drafts for the treadle loom or floor-loom are WIF file; WIF stands for Weaving Information File. It is a standard file for sharing weaving files among different weaving programs. It is simple text file that describes a weaving project. Using WIF files, weavers can electronically store and exchange weave-drafts, display them graphically with weaving software, and use them to drive computer-assisted looms. It also makes it possible to elegantly publish weave-drafts with very long repeats in the threading and treadling. WIF represents a unique collaboration between the programmers of major software packages available to hand-weavers today. The first version of WIF is version 1.0, it was released March 3, 1996 and the current version is 1.1 which was released April 20, 1997. The advent of this file standard opens the door for weavers and artists to share their work freely without the limitations of particular software's file format. It also allows weavers to work with their designs using several different programs.

Historical and Technical Details of WIF
In the 1990s, developers of weaving software recognized that there was a need for a common file format to describe a weaving project. Until then, each weaving program has its own proprietary way of storing weave-drafts. This meant that weavers using different software could not share files. So in March of 1996, a specification for the WIF file format was published, it is based on the windows INI file format. The idea was that weaving software developers could use this specification to write import and export functions that would enable weavers to share weave-drafts between different weaving programs. For more detail of WIF file check in [64] [8].

2.4.3 Weave structures

There are many weave structures were developed by weavers, but the most of them were invented by a combination of three simple weave structures namely: plain weave or tabby, twill and satin. However, a main weave technique used for making traditional Lao textiles is a compound weave; its weave structure is a combination between plain weave and supplementary weft pattern weave. Therefore, in this section we will give only brief explanation of fundamental weave structures that are related to constructing Lao woven fabrics. The description of each weave structure was summary from textile books [26][84] and a study material [48].

Plain weave or Tabby: is used to link all the warp threads together. Plain weave is placed between the picks of design, otherwise the material would not hold together properly. Plain weave is then usually woven with a very fine thread, similar to the warp thread, since it should not be seen as it is not included in the design. Depending on the method used or the design to be achieved, a plain weave shot can be thrown after each design pick, which is usually done, or it can be woven after two, three or even four weft threads, this varies with the crossing of warp threads and weft threads and the length of the floats in the warp. Usually a plain weave pick (one shot of plain weave from the right hand side, the next shot of plain weave from the left hand side) is thrown between the repeated picks of the design in colored thread.

Twill weave: each warp passes over or under more than one weft and each weft over or under or under more than one warp in the interlacement sequence. The minimum number of threads required for a twill interlacement is therefore three warp ends and three wefts (the weft passes over one warp and under two or over two warps and under one). Each successive pick begins the same interlacement on an adjacent warp end, either to the left or to the right, creating a diagonal line.

Satin weave: a simple weave with warp floats on one surface of the cloth and weft floats on the other. The order of interlacement of warp and weft is regular and dispersed: no two adjacent warps or wefts interlace. Warp ends and weft picks pass over or under every thread but one in the repeat. Shafts are usually threaded in straight order beginning with the first shaft and ending with the last shaft.

Supplementary weave: is a decorative technique in which additional threads are woven into a textile to create an ornamental pattern in addition to the ground pattern. The supplementary weave can be of the warp or of the weft**.**

Supplementary weft pattern weave: also called extra weft, pattern weft, supplementary weft, a structurally non-essential weft used to add pattern to a ground structure. This weave technique in Lao called *"Tam Chok"*, it is a main used technique for making traditional Lao textiles.

Supplementary warp pattern weave: also called extra warp, pattern warp, supplementary warp that weaves in on the top of the background fabric or below depending on how it is treadled. This technique in Lao called *"Tam Mouk"*.

Compound weave: contains more than one weaves structure.

2.5 Literature reviews

Cultural heritage is a valuable treasure that should be studied, promoted and preserved to the next generation. The publication of [17] mentioned that traditional hand woven textile is a cultural heritage. It indicates culture, livelihood, creativity and intelligence of ancient people. Motifs and patterns on the textiles not only show craftsmanship and aesthetics, but they describe the fundamental principles of living, tell story and explain the religious beliefs of people. These factors are main influence to archaeologists, mathematicians and scientists to investigate cultural and scientific contexts of traditional textiles. The role and technical use of traditional woven textile was considered and studied by scholars in many countries, such as Malaysian [76], Thailand, India and Lithuanian. The study from [21][73][40] revealed the role of hand woven textile and the belief of people who lived in central part and Northeastern part of Thailand, where the most of inhabitants were migrant Laotian people. Anasee Pengsaa Stone [4] investigated Isan Textiles in Northeastern Thailand with particular reference to design and manufacturing strategies. Furthermore, Franco Amantea [24] investigated dress and identity of Black Tai (Tai Dam) ethnic group of LOIE province. The traditional ethnic woven textile in Manipur of India was studied in [3]; the inhabitants in this region had cultural similarities to Southeast Asia's cultures. The result of study revealed the impact of social change incorporated with modern technology that caused the traditional woven textile of Manipur were rapidly changing in terms of designs, motifs, yarns and processes. The study of textile heritage of Lithuanian offered that ethno cultural heritage are important and valuable, today the motifs of ethnic ornamentation, practical and symbolical uses of authentically folk fabrics are coming back. Traditional woven textiles of Lithuanian had been investigated since 2006 [32], which was a study of the peculiarities of the ornamentation of Lithuanian traditional woven textiles within all ethnic regions. [21] [22] [23] [74] particular investigated Lithuanian folk skirts by study of patterns, weaves, variety and prevalence of skirts, as well as the peculiarities of their color combinations and weaves. The analysis of ornamental symmetry was based on the geometrical characteristics governing the structures of the designs, the most the resources of their analysis were from the National Museum of Art.

The relationship between culture and science of design was one of interesting fields to researchers. Dorothy K. Washburn and Donald W. Crowe [17][18] explored meaning and the role of visual symmetry in human cultures; patterns and symmetries were deeply studied, while the influence of the symmetries to human cultural formation and identity was analyzed as well. The study of symmetry and human culture was represented again by W. Vandamme [85] which was a review of Dorothy K. Washburn's work. The particular investigation on Islamic arts found on [49][38][52] which illustrated classifications and analysis's results of the geometric structures of the Islamic arts, the results revealed that the most two-dimensional patterns of the arts were symmetrical patterns. In addition, the particular analysis of geometries of representative groups of designs was presented in [16][19]; the publication offered the communicative importance of design that could be used to check symmetry groups of design. The examination on the use of mathematical symmetries in various ethnic woven fabrics of Philippine [54] was an example to show the relationship between cultural woven textiles and mathematical symmetries. The examination applied geometric structures presented in [16] as a tool to determine and analyze the one-directional and two-directional symmetry groups of patterns appearing on the woven fabrics.

The additional studies of the geometrical basis for pattern design (including textile patterns) were presented by H.J. Woods [29][30][47], and M.A. Hann and B.G. Thomas [46]. Especially, [46] expressed various geometric concepts, principles and constructions which were of great value to researchers and practitioners. Their intention focused on the use of geometric symmetry as a basis of an analytical tool to examine designs in different cultural or historical contexts. An application of this analytical tool showed in [42], which was a research for analysis the relationship between woven ornamentation and the technology used for construction of traditional Greek textiles. However, the distinction of two-dimensional symmetry groups for non-Jacquard woven design (including hand woven textiles) was explained by V. Milasius, etc [81]. The geometrical features of woven ornaments were analyzed and then basic constraints on the fundamental geometrical rules of creation of woven ornaments were brought out. The study concluded that only twelve of the seventeen two-directional symmetry groups can be used for the description of non-Jacquard woven ornaments.

Since binary matrices and binary images are fundamental representation of weave structures, there were many researchers investigated woven textiles based on their attributes. [80] was extended publication of V. Milasius; it presented a computerized creation of woven ornaments based on binary matrix multiplication. It also implemented symmetry groups for analysis and synthesis of the ornaments of woven fabrics. An additional publication was [87]; it presented mathematical modeling of traditional graphics structures within textile materials using binary matrices for weaving design construction. Due to modern weave technologies often work with digital weave-drafts, so the most found textile preservations were archived in digital forms, such as digital archiving of traditional Songket motifs of Malaysia [57] and database of national Lithuanian woven fabrics [35]. Therefore, there were many investigations on dealing with digital patterns. [56][55] presented noise removal techniques and enhance binary image of woven textile, and then compared their results. [6] presented filtering methods for pattern segmentation in textile images; [69] compared image processing techniques for textile texture images by comparing performance of Contrast adjustment, Intensity adjustment, Histogram equalization, Binarization and Morphological operations.

Regarding the importance of cultural heritage and the lack of modern weave technology of Lao weavers, we conduct this interdisciplinary research which is a combination of three different fields. The first field is culture of Lao textiles by considering on the significance of the culture. Secondly, it is a science of design and lastly it is a scientific computing for digital drafting and digital weaving. We start the research by collecting antique and contemporary textiles for analysis. After that, we investigate the needs and limitations of local weavers in order to fill the gap between weave techniques used in Laos and the current weave technology. As a result, this research developed three design modules by intention to satisfy technical weaving of local weavers and to compatible to modern weave techniques. Each module aims to provide specific purpose. Mathematical Symmetries are mainly implemented for motif and pattern designs, while image processing techniques are investigated to support digitizing motifs. In addition, we developed algorithms of weave-drafts based on traditional weave techniques used in Laos and widely used for electronic looms. The weave-drafts are intended to understandable for hand-weavers and electronic looms. Lastly, we developed online repository to store digital motifs, patterns and textiles. The detail of methodology, mathematical concept and scientific algorithms are going to explain in the next chapter.

Chapter 3

Analysis and Methodology

This chapter will start from the details of field trips to Laos for collecting samples of Lao textiles. The collection will be presented in three different categories, based on type of textile item, ethnic group and location. After that the mathematical symmetry groups for motif and pattern analysis will be introduced. We will introduce three diagrams for wallpaper pattern classification; the diagrams are constructed by regarding characteristics of symmetry groups that belong to the wallpaper group. The second part of this chapter will explain the mathematical representation of weave components and weave structures. Then the explanation of methodologies and algorithms for digitizing motif, pattern and weave-drafts will be the last part of the chapter.

3.1 Field Trips to Laos

Due to the research directly relate to cultural heritage of Laos, samples from local are necessary data to support the performance of research. In terms of tradition, motifs and patterns decoration, and the use of textiles always involve to religious belief, they often hide meaning. The most traditional motifs were created based on the beliefs of Buddhism and shamanism. In order to get such data, it is necessary to conduct field trips to Laos. The data from field trips is important to contribute cultural preservation. The samples of textiles are good references and main support to construct data models of motifs and patterns. As a result, we totally took 3 field trips to Laos for interview local weavers, collecting data and digitizing data models. Each field trip held one month period. The first trip started in August 2012; it mainly aimed to collect samples of textiles in central part of Laos. The second trip held in between August and September 2013 to operate a small project for digitizing data models. The last field trip was in August 2014, the aim of the trip was to collect more samples of traditional textiles from various parts of Laos. The details of each field trip will be explained in following section.

3.1.1 Excursion 1: August – September, 2012

The purpose of the first field trip was to collect data of traditional textiles by interview local weavers and taking photographs of samples, especially the samples of motifs and patterns; we additionally bought few samples of hand woven textiles. The samples were locally collected in Vientiane capital which is a central part of Laos. The required data for the interview was related to religious beliefs, meaning of designs and technical use in weaving. Targets of places for data collection were divided into four groups namely: weaving villages, textile manufactories, a textile museum and a textile market. Types of textile items were various from place to place. The production of textiles in the villages mainly was for trading to earn little income to family, the most products were skirts *"Sihn"*. The designs were copied from antique and contemporary textiles, the master patterns and weave-drafts were stored in traditional way.

The most various types of textile items were found in a gallery of Phaeng Mai manufactory. The textile items were assembled from various ethnic groups, for instance, mosquito-net and head-cover cloth of Tai Daenge ethnic and shawl of Phou Tai ethnic. The Phaeng Mai manufactory only produced hand woven textiles; the design of motifs and patterns were traditional and contemporary styles. The productions of the manufactory were intended to contribute to cultural preservation. Therefore, we got a lot of traditional data of the textiles provided by a head of design and marketing of the manufactory. Lao textile museum was another place that exhibited a variety of ethnic textiles and textiles from both Buddhism and shamanism, such as, banner of shamanism, manuscript's cover of Buddhism. So, we got a variety of samples and traditional data of the textiles provided by the owner of the museum.

In order to compare traditional weave technique to weave technology used in Laos, we visited Lao Cotton Company. The company was only one Textile Company in Vientiane capital that applied electronic looms for fabrics production. The purpose of visiting was to explore weave technology used in the company. A policy of the company was to keep design and traditional style of Lao textile and use electronic looms to produce fabrics. The company consisted of three electronic punch-card Jacquard looms, and five electronic shaft looms. A head of production department mentioned that the electronic looms used in the company were very old models. In future the company expected to implement modern electronic looms for production. The company required a technique to support drafting and weaving fabrics and keep traditional Lao style. The information from the company showed a limitation of weave technology in Laos; a connection between traditional weave technique and modern weave technology was high requirement to support production. The last place of the field trip was Khuoadin market; it was one of the biggest textile markets in Vientiane capital. Getting data from the textile market helped us to explore a trend and a difference of design from different areas. A variety of traditional and contemporary textiles found in this market. According to the data showed that the trend of design was more for aesthetics than for traditions. The design from north was more complicated than the design from the south. In addition, we found lot of imported textiles from neighboring countries; the imported textiles simulated traditional motifs, pattern styles without respect original products. The data implied long term effect of traditional Lao textiles from the imported textiles if the related organization omitted this issue.

The data from this field trip was a main source to analyze characteristics of Lao textiles, and to construct digital data models of the research. In the next section, we will explain details of a digitizing project that held in the second field trip.

3.1.2 Excursion 2: August – September, 2013

Digital data models of traditional motifs and patterns of Lao textiles are significant for cultural preservation and for connection to modern weave technology. Therefore, a project for digitizing data models was required in order to construct a variety of digital antique motifs by using Lao Textile (LT) design modules that created in this research, LT-Tieup module aimed as a main tool for digitizing motifs (a development of the LT-Tieup module is presented in section 4.1 in chapter 4). The most input data for the project was photographs of motifs and patterns from the first field trip. Because a complexity of motif's structures and pattern's design, the project needs assistants who have basic knowledge in weaving and are able to use the design modules to construct digital motifs.

As a result, the second field trip to Laos was approved to setup a small project for digitizing data models (mathematical concepts and algorithms for digitizing will be explained in section 3.3). The project was cooperation between Heidelberg Graduate School of Mathematical and Computational Methods for Science (HGS MathComp) at the Interdisciplinary Center for Scientific Computing (IWR) of the Ruprecht-Karls University at Heidelberg, Germany and the Faculty of Natural Science (FNS) of National University of Laos (NUOL), Laos. The project took one month period in FNS and provided two assistants who were junior lecturers from computer science department. The aim of the project was to construct digital motifs that followed the same weave structure as showed in the original designs. Results of digitizing were formatted to standard weaving files. However, a diversity of photos' resolutions and a complexity of designs were difficulties for digital motifs construction. According to characteristics of traditional motifs, we separated the motifs into lined motifs and single motifs which will be explained more detail in section 3.3.1.1 and section 3.3.1.2 respectively. The original motifs were carefully analyzed before using the LT-Tieup module to reconstruct their digital forms. Because *Naga* motifs were identity symbols of traditional Lao textiles, there were more than 50 motifs of *Naga group* were constructed. Moreover, there were more than 10 motifs of *Siho*, *Giant* and *Bird* groups were constructed, as well as some common lined motifs were created.

The digitized motifs from the project will be stored in a website that developed in this research (a concept of the website development is explained in section 4.5 in chapter 4). Furthermore, they will be used as primitive objects for new design by embedded them as predefined motifs in the LT-Tieup module. However, the samples from the first field trip and the digitized data models from the second field trip were insufficient to express characteristics of traditional Lao textiles. Therefore, we needed more widely data from different part of Laos. The previous data were only collected in central part of Laos; the third field trip was required for getting more data and to explore the difference of the textiles in different areas. Details of the last field trip will be explained in following section.

3.1.3 Excursion 3: August – September, 2014

The aim of the third field trip was to get more data in southern and northern Laos. Targets of visited places in the south were Champasak province and Savannakhet province. The travelling began to visit Saphy Handicraft Center in Champasak province, the center was established for promotion and contribution to local hand woven textiles. The textile products were assembled from weaving communities in the surrounding areas. The most of the products were *Sihn* and *Pha being* (narrow shawl). Based on observation showed that the most copied from nature and decorated by simple structures; the patterns were various from small to medium sizes. In Savannakhet province, we visited a weaving village which was promoted to development of provincial tourism. The village also contributed to the preservation of using traditional weave technique. Unfortunately, the weave technique used in the village was ikat or *"Mat Mii"* which was out of research's scope.

The destinations of data collection in the north were Houaphan province and Luang phabange province. Houaphan province is a well-known place as a source of shamanic textiles, almost Tai Daeng and Tai Dam ethnics live in this province. We visited Sam Neua which a city of Houaphan province. Sam Neua was a highlight of the trip; we found a variety of religious motifs and patterns. According to interviews of local weavers, the textiles were not only woven for shamanic rituals, but they also were products for daily use and for tourists market. The products of textiles were not only to sell in local market, but they were also sent to markets in Vientiane capital and Luang phabang province. The decoration style of Sam Neua textiles was complicated and colorful, in one fabric contained various traditional motifs, for instance on a *Sihn* might consist of *Siho, Giant, Bird, Naga* motifs and others small motifs. Luang phabang province was a final destination of this field trip, Luang phabang is world heritage site, has been promoted since 1995. Therefore, a variety of crafts and traditional products can be found in here. We visited Phanom Handicraft Centre in Phanom village of Luang phabang province. The centre was found in 1996 and supported by the government of Lao PDR. It was contribution to development of provincial tourism as well as increased income and jobs for the local weaving communities. It also contributed to the preservation of Lao weaving culture and traditional silks. Therefore, the center consisted of 80 textile shops. The products were from local weavers in Phanom village, from weaving communities in the surrounding areas and from weavers in remote areas. The most local weavers were Tai Lue ethnic, they were Buddhists, the motifs and patterns on their textiles represented belief and faith in Buddhism. Structure of Tai Lue motifs were less complicated than structure of shamanic motifs and Sam Neua motifs.

The data from this field trip revealed the difference of design of various ethnic groups in the south and the north of Laos. The motifs basically copied from environments and religious beliefs. Therefore, the data from three field trips are sufficient to identify characteristics of traditional Lao textiles and to support for cultural preservation. Collections of the samples can be represented in three categories based on types of textile items, ethnic groups and locations. In next section we will explain details of the samples distribution in each category.

3.1.4 Samples Collection

The collection of samples is from traditional and contemporary textiles. The traditional textiles are original textiles from ethnic groups; their decoration and their use are for rituals. In contrast, the contemporary textiles are decorated by a combination of traditional motifs from various ethnic groups; their decoration is for aesthetic and they can be used in any occasion. The samples are not only from the field trips, but some of them are from books and online sources. Due to the style of Lao textiles often decorated with a numerous motifs and a variety of pattern's sizes; in a textile contains many motifs and patterns. Therefore, we separate the collection into three types namely samples of motifs, patterns and textiles. The samples of motifs and patterns support not only data for archiving, but they additionally provide data for the development of design modules which is one of the objectives of our research. They play important role for motifs and patterns analysis that will be explained in section 3.2. Furthermore, the samples are collected from three main parts of the country; they represent textiles of ethnic groups. As a result, we will present the collection of samples by three categories in order to describe a distribution of the samples in each category. Firstly, we category the sample based on types of textile items, the second category is classified based on ethnic groups and the last category is classified based on locations.

The category of the samples classified by types of textile items is illustrated in table 3.1 and a visual data of the samples is shown by a bar chart in figure 3.1; the category contains 10 types of items and a group of unknown type. Basically, the samples of the unknown type were from traditional textiles; the most of them were taken from secondary sources, such as textile books and websites of Lao textiles. Due to traditional Lao motifs are big and complicated in design; the motifs are often decorated in central area of the textiles. From these characteristics, the motifs become the most interesting part of the textiles. Therefore, the authors of some sources ignored item type and

No.	Item type	Amount	Percentage
1	Blanket	12	2.05 %
2	Coffin cover cloth	5	0.85 %
3	Curtain	10	1.71 %
4	Cushion cover cloth	3	0.51 %
5	Head cloth	13	2.22 %
6	Mosquito net	5	0.85 %
7	Shawl/shawl hem	133	22.74 %
8	Skirt/skirt hem	361	61.71 %
9	Shaman bag	1	0.17 %
10	Tapestry	6	1.03 %
11	Unknown	36	6.15 %
Total		585	100.00 %

Table 3.1:
Types and number of collected samples

pattern of the textiles, the authors only focused on the appearance of the motifs.

Table 3.1 presents a list of item type, number of the samples and their relevant percentages. Since skirt (*Sinh*) and shawl are main products of Lao textiles, the sources of both skirts and shawls are from traditional and contemporary textiles. Thus, the number of skirt is very high when comparing to other items, it takes 61.7% of the samples. The number of shawl is in the second level, it covers 22.74% and it is approximately triple lower than number of the skirt. The bar chart in figure 3.1 clearly illustrates the different amount of the items. The number of unknown type is in the third level, but its amount is very different when compare to the first and the second levels. The amount of household and ritual's textile is also very different when compare to the number of skirt and shawl, the most of them were collected from Lao textile museum and Phaeng Mai gallery. Because of a change in society and lot of cheap industrial households are available in markets, local weavers prefer to buy rather than to spend their time for producing items by themselves. The shamanic items for rituals, such as coffin cover cloth, head cloth and shaman bag are still woven in rural areas, but they are used for specific rituals. Nowadays shamanism takes a little amount while Buddhism roughly covers 90% around the country, this is reason why number of shamanic item is very low.

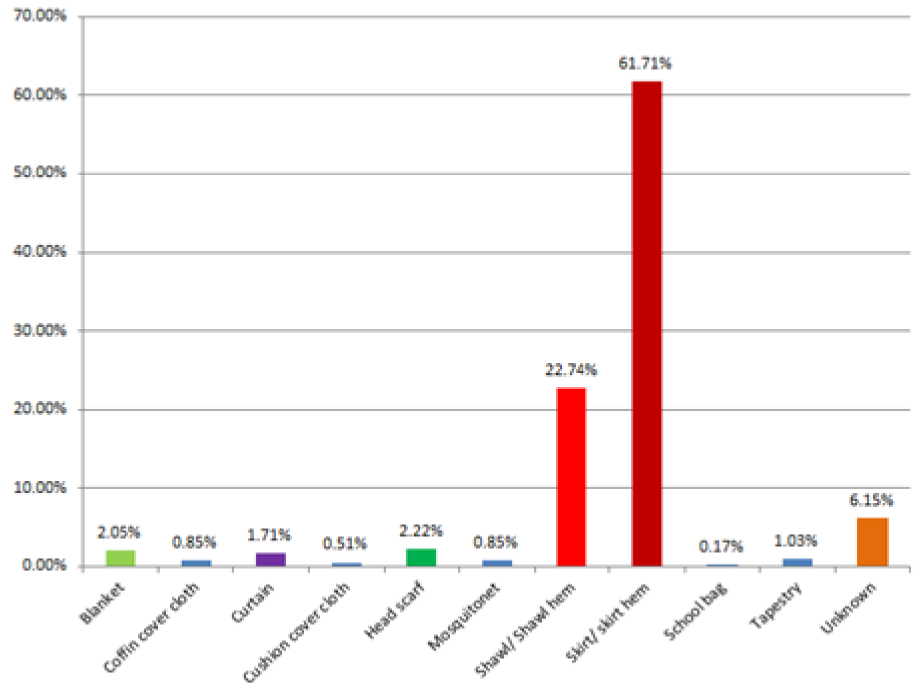


Figure 3.1
Types and number of collected samples showed in percentage

In the second category, we classify the samples based on ethnicity. We totally get the samples from nine ethnicities and a group of unknown ethnic name. Table 3.2 shows the list of the ethnic name, the amount of the samples and their corresponding percentages. Figure 3.2 visualizes a difference among the samples of ethnic textiles. A bar chart in the figure 3.2 clearly shows that number of Tai Lue sample is the highest. It takes 41.31% of the samples. The most Tai Lue samples were from Luang phabang and from the second field trip. Shamanic textiles of Tai Daeng and Tai Dam have the most complicated design among ethnic textiles. The reputation of Tai Daeng and Tai Dam people in weaving skill is well-known among weavers and local textile researchers. Therefore, the numbers of their samples are in second and forth levels respectively. Lao Loum people are Buddhists and they are in the biggest group who live along Mekong River and river banks in lowland areas. The samples of Lao Loum textiles were mainly from Saphy Handicraft Center in Champasak province, as we can see their number gets third level by 13.62% of the samples. Actually Tai Phuan and Phou Tai women are skillful in Ikat weave technique, but the target of our collection is motifs and patterns from Tam Chok. Thus, the number of their textile samples in this collection is quite low when compare to Tai Lue, Tai Daeng, Tai Dam and Lao Loum.

No.	Ethnic Name	Amount	Percentage
1	Lao-Loum	87	13.62 %
2	Phou Tai	6	0.94 %
3	Tai Daeng	153	23.94 %
4	Tai Dam	76	11.89 %
5	Tai Khao	1	0.16 %
6	Tai Lue	264	41.31 %
7	Tai Moy	2	0.31 %
8	Tai Phuan	10	1.56 %
9	Tai Thaeng	1	0.16 %
10	Unknown	39	6.10 %
Total			100.00 %

Table 3.2
Ethnic groups and number of collected samples

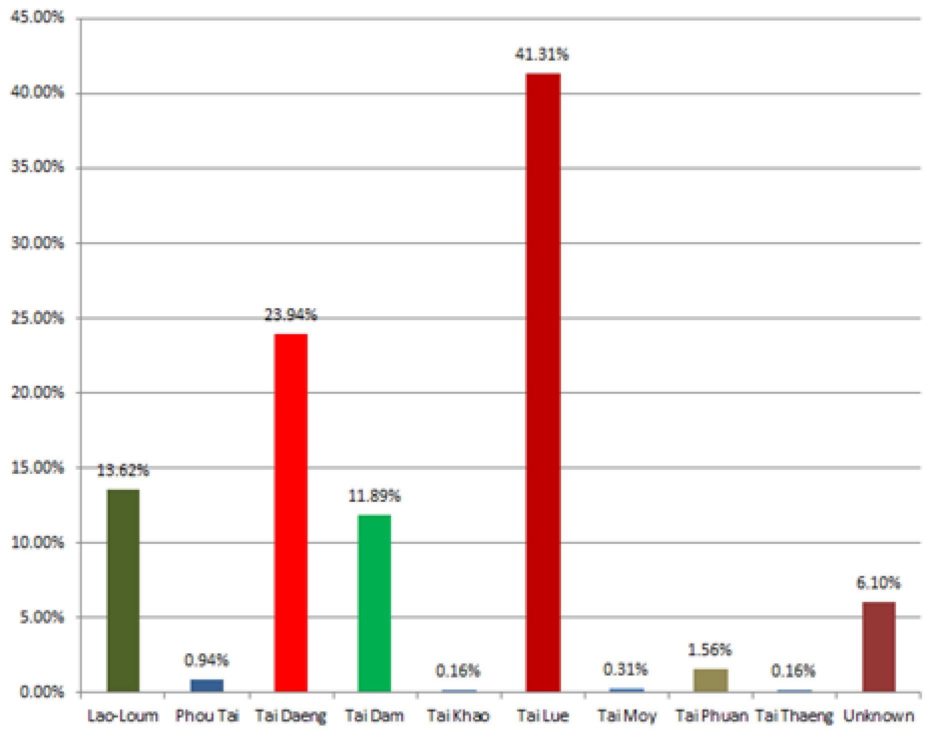


Figure 3.2
A collection of ethnic textiles and their corresponding percentage

For the last category, we classify the samples based on their locations in order to show the variation of the samples in different areas of the country. We get the samples from 11 provinces of totally 17 provinces of Laos, and a group of unknown location. Table 3.3 shows the list of provinces, the amount of the samples in each location and their relevant percentages. Figure 3.3 illustrates that the samples are mainly from four provinces and a group of unknown location. Luang phabang is the first level with 43.10%, Houaphan is the second level by taking 22.56%, Vientiane Capital and Champasack almost get the same level. It only 0.16% different, they are third and fourth levels respectively while the unknown location is fifth level by taking 7. 58% of the samples.

No.	Location (Province)	Amount	Percentage
1	Bokeo	4	0.67 %
2	Bolikhamxay	2	0.34 %
3	Champasak	57	9.60 %
4	Huaphanh	134	22.56 %
5	Khammuance	4	0.67 %
6	Luang Prabang	256	43.10 %
7	Louangnamtha	2	0.34 %
8	Oudomxay	13	2.19 %
9	Savannakhet	5	0.84 %
10	Vientiane Capital	58	9.76 %
11	Xieng Khouang	14	2.36 %
12	Unknown	45	7.58 %
Total		100.00 %	

Table 3.3
Textiles locations and number of collected samples

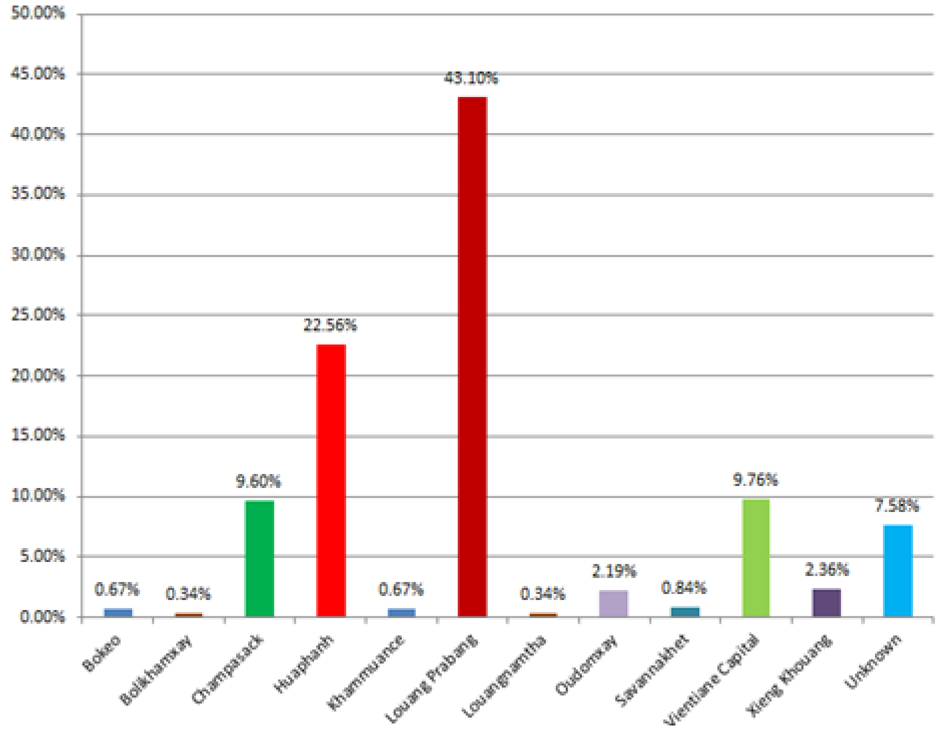


Figure 3.3
Locations of collected textiles and their corresponding percentage

3.1.5 Summary on Field Trips

The field trips are main factors to process and accomplish the research. Due to the most required data are in Laos, the data and samples from the field trips provide accuracy, reliability and increasingly quality to the research. From three field trips, we got a lot of data that will be summarized in this section. Firstly, it was traditional data that is necessary for archiving; for example, meaning of motifs, pattern's styles and the use of ethnic textiles. Secondly, we got numerous samples of motifs, patterns and textiles that play important role in archiving and digitizing. The samples were collected from the north, central part and the south of the country, the collection consisted of various ethnic samples. The three categories of the samples presented in section 3.1.4 showed that if we categorized the sample by type of item then skirt was the most found item. If we categorized the sample by ethnicity then Tai Lue was the most found ethnic group. Finally, if we categorized the sample by location then Luang Phabang was the most found location. In addition, the data from the field trips also implied a conflict of design between Lao textiles and imported industrial textiles. The data also revealed the limitation of weave technique in Laos; we found a gap and a requirement to connect traditional weave technique to modern weave technique.

In conclusion, this research is directly involved to cultural preservation that required a lot of data from Laos. The data from three field trips are useful and necessary; they fulfill the most requirements of the research. Therefore, this research would not complete if it lacked of data from the local. In the following section we will move to analysis section to analyze geometrical structures of motifs and patterns.

3.2 Pattern Analysis

The analysis aims to find out common symmetry groups on traditional Lao textiles. The analysis of textiles and their components will help to understand their characteristics and their design styles. We define Frieze pattern as one-directional pattern and wallpaper pattern are two-directional pattern. A Frieze group is a discrete group that contains symmetry groups for generating Frieze patterns; similarly wallpaper group is a discrete group that contains symmetry groups for generating wallpaper patterns. The analysis result will be data to support for developing design modules, the geometric structures for each symmetry group are aimed to construct within the modules in order to introduce more design styles to the Lao weavers.

To analyze Frieze patterns and wallpaper patterns on Lao textiles we apply the geometric principles of seven symmetry groups in Frieze group and twelve of seventeen symmetry groups in wallpaper group [86] [62]. The notation for each group, we use international notation from crystallographic groups (IUC: International Union of Crystallography) [15]. Moreover, symmetry groups of Frieze group we use names that are given by John Conway. In general Frieze and wallpaper patterns are generated by a combination of four basics symmetry operations namely: translation, rotation, reflection and glide reflection. Frieze patterns are generated by repetitive translation a motif in one direction while wallpaper patterns are generated by repetitive translation a motif in two directions. Therefore, we explore symmetry group on the textiles by studying symmetric structures of the patterns, we construct diagrams that based on the symmetric structures of each group, so the constructed diagrams are used as guidelines for checking patterns' structure and classifying their belonging symmetry group.

3.2.1 Frieze Pattern Analysis

Four symmetry operations are important in the context of two-dimensional design: translation, rotation, reflection and glide-reflection. Combinations of the four symmetry operations yield seven distinct subgroups in the discrete frieze group generated by a translation, reflection (along the same axis) and a 180 degree rotation. Each of these subgroups is the symmetry group of a frieze pattern, a schema to illustrate their pattern shows in figure 3.4. Table 3.4 lists some components of Frieze groups that are important for diagram construction, such as: group name, notation and their description. The diagram for checking frieze groups illustrates in figure 3.5, the diagram helps to check a combination of symmetry operations among the groups. Actually, the seven symmetry groups of Frieze group can be applied for woven pattern, but the pattern style on traditional Lao textiles is related to tradition and religious beliefs of local people. Thus, there is some symmetry groups of Frieze groups did not found on the Lao textiles. The analysis result of Frieze patterns on traditional Lao textiles illustrated that six of seven Frieze groups found on the textile's samples, they are *Spinning Jump (p2mm), Jump (p11m), Sidle (p1m1), Hop (p1), Spinning Hop (p2)* and *Spinning Sidle (p2mg).*

No.	Group Name	IUC Natation	Description
1	Hop	p1	only translations
2	Sidle	p1m1	Translations and reflections across certain vertical lines
3	Jump	p11m	Translations, the reflection in the horizontal axis and glide reflections
4	Step	p11g	Glide-reflections and translations
5	Spinning Hop	p2	Translations and 180° rotations
6	Spinning Sidle	p2mg	Reflections across certain vertical lines, glide reflections, translations and rotations.
7	Spinning Jump	p2mm	Translations, glide reflections, reflections in both axes and 180° rotations.

Table 3.4
Group name, notation and short description of Frieze group

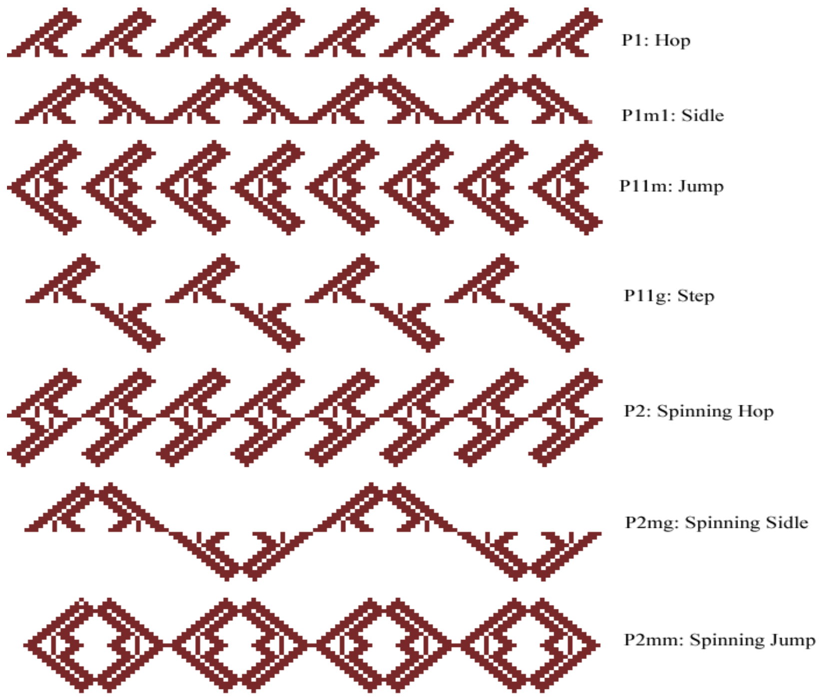


Figure 3.4
Schematic illustrations of the seven symmetry groups of Frieze group

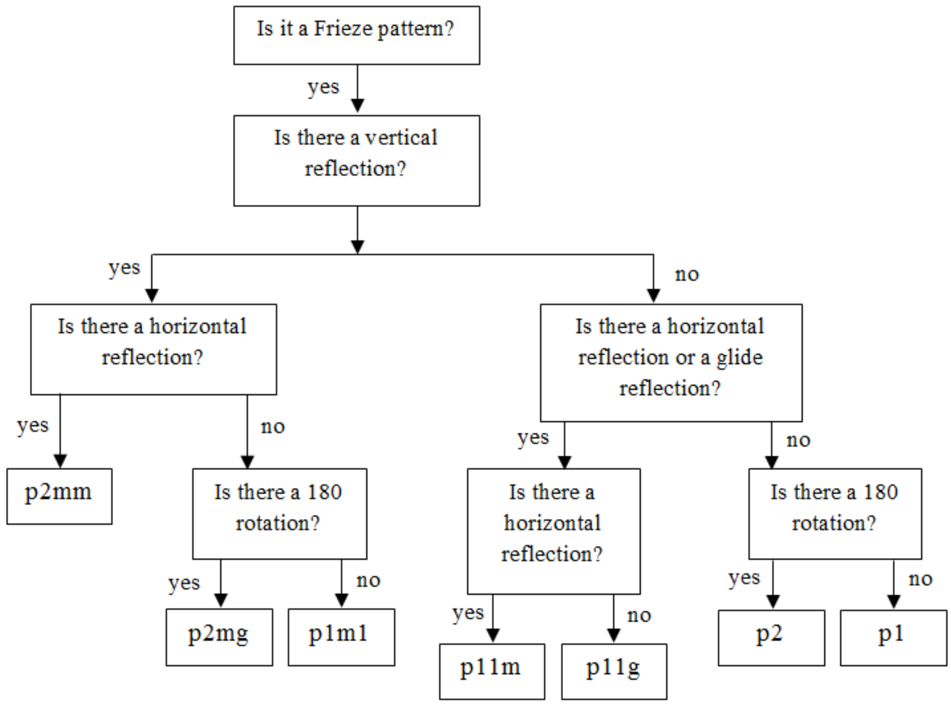


Figure 3.5
A diagram for Frieze Pattern classification based on seven symmetry groups

3.2.2 Wallpaper Pattern Analysis

Due to restrictions of weave structure, a woven motif cannot contain rotation in 60 and 120 degrees. This means that the woven pattern cannot contain rotation order of 3-fold and 6-fold. Therefore, five symmetry groups of wallpaper group cannot be applied, there are only twelve possible symmetry groups can be applied for woven pattern decoration. This limitation illustrated by V. Milasius [80]. Since the combination of symmetry operations in the wallpaper group is more complicated than in the Frieze group, table 3.5 lists some components of wallpaper group that are important for analysis, such as: the notation, lattices used and description of each symmetry group. Because the research focuses on traditional style of Lao patterns, we use only two of 5 different lattices' types for generating wallpaper patterns, such as

No.	Notation		Rotation orders	Lattices used	Description
	Full	Short			
1	P111	p1	1	Rectangle, square	Contains only translation
2	p211	p2	2	Rectangle, square	Contains translation and rotation order 2
3	p1m1	pm	1	Rectangle, square	Contains translation, reflection, but no glide reflection
4	p1g1	pg	1	Rectangle, square	Contains translation, glide reflection, but does not contain rotations or reflections
5	c1m1	cm	1	Square	Contains translation, reflection and glide reflection
6	p2mm	pmm	2	Rectangle, square	Contains at least one reflection
7	p2mg	pmg	2	Rectangle, square	Contain reflection, there is no reflections in two direction
8	p2gg	pgg	2	Rectangle, square	Contain only two orders rotation
9	c2mm	cmm	2	Square	Contains vertical and horizontal reflections
10	P411	p4	4	Square	Contains translation and rotation of order 4
11	p4mm	p4m	4+	Square	Contains at one reflection
12	p4gm	p4g	4*	Square	Contains diagonal glide reflection and four orders rotations

Table 3.5 Group name, notation and short description of wallpaper group
12 symmetry groups and their symmetries (adopted from [15]). Here '+' means all rotation centers lie on reflection axes, and '*' means not all rotation centers on reflection axes.

rectangular and square lattices. A fundamental parallelogram of pattern is created based on those two lattice types. We separate symmetric structures of the wallpaper group into three categories based on number of rotation order that contained in the groups, and then we constructed three related diagrams. The first diagram is for 1-fold rotation order where there are totally 4 symmetry groups in this case, they are cm, pm, pg and p1. The diagram is illustrated in figure 3.6 and its corresponding schema is shown in figure 3.7.

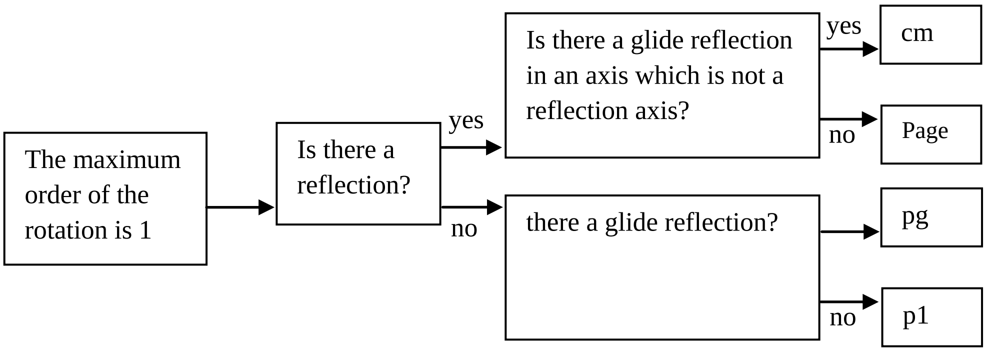


Figure 3.6
A diagram for wallpaper pattern classification when the maximum order of the rotations equals to one

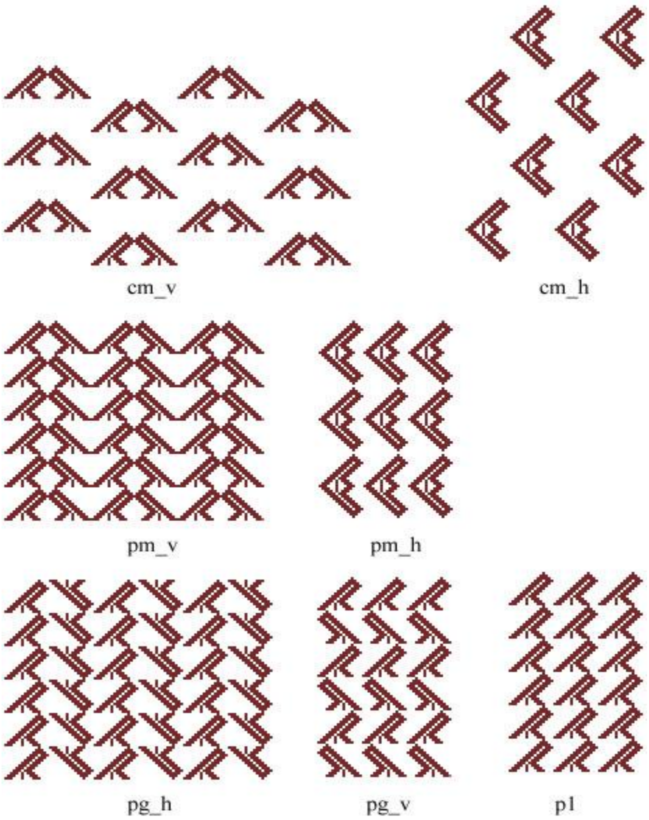


Figure 3.7
Schematic illustrations of the wallpaper patterns generated by maximum order of the rotations equals to one

The second diagram is for 2-folds rotation order that includes 5 symmetry groups in the diagram, such *pmm*, *cmm*, *pmg*, *pgg*, and *p2*. Figure 3.8 illustrates the diagram while figure 3.9 shows its corresponding schema.

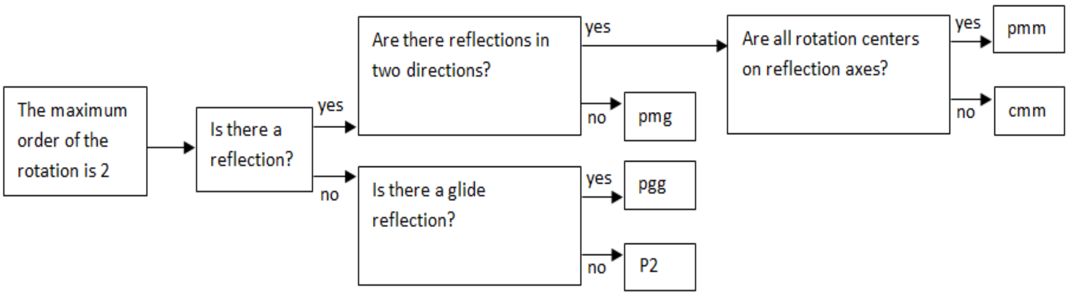


Figure 3.8
A diagram for wallpaper pattern classification when the maximum order of the rotations equals to two

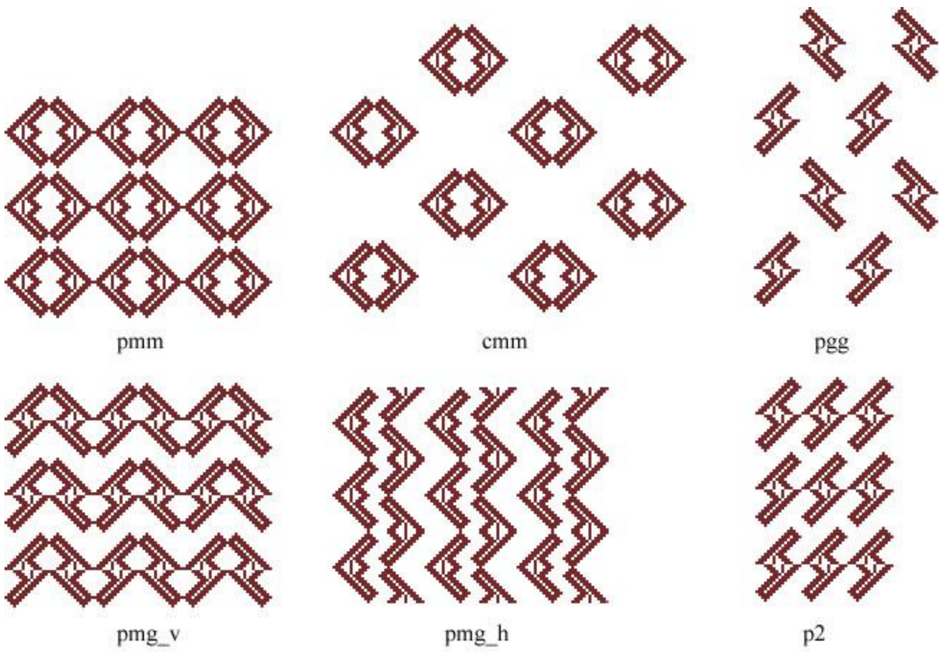


Figure 3.9
Schematic illustrations of the wallpaper patterns generated by maximum order of the rotations equals to two

The last diagram is for 4-fold rotation order that consists of only three symmetry groups, namely, *p4*, *p4m* and *p4g*. It is presented in figure 3.10 and its schema is presented in figure 3.11. Because the most traditional motifs are quite big and some of them are symmetric, the wallpaper group cannot apply to them. As a result, the most found symmetry groups of wallpaper patterns on the samples were applied to small and medium motifs. Unfortunately, we found only four of twelve symmetry groups on the samples namely *pmm*, *cmm*, *pm* and *p1*.

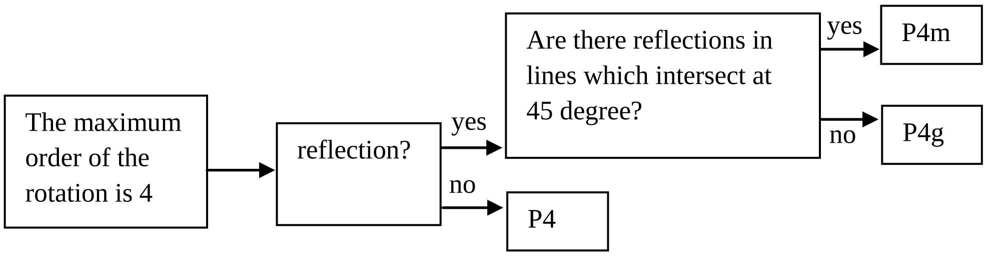


Figure 3.10
A diagram for wallpaper pattern classification when the maximum order of the rotations equals to four

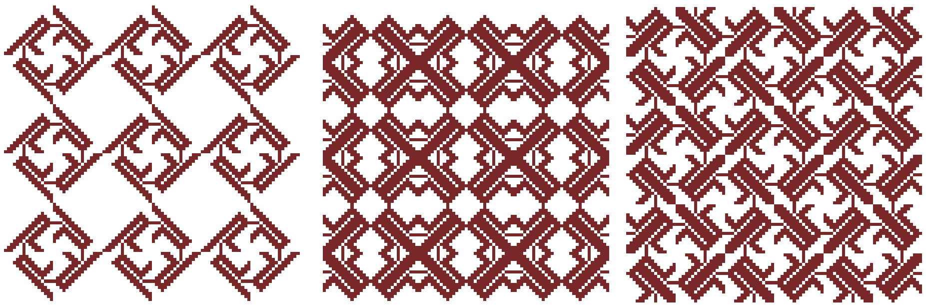


Figure 3.11
Schematic illustrations of the wallpaper pattern generated by maximum order of the rotation equals to four

3.2.3 Motif and Symmetry

In terms of weave design, a motif is one repeat pattern which does not apply translation operation. This type of design is called finite design; the design can have only reflection and/or rotation symmetry [11]. These designs fall into two groups, the *cyclic* group denoted by *cn* and the *dihedral* group denoted by *dn* where *n* is some integer. The designs of the *cyclic* group are those have n-fold rotational symmetry, but no mirror symmetry. The designs of the *dihedral* group have reflection symmetry as well as n-fold rotational symmetry. In fact, it is unlimited value for number *n* for design printed textile, it depends on the creative of designers, but it is limited number of *n* for design woven pattern. According to the study on woven pattern [80] showed that there are only three possible rotational degrees (90, 180 and 270 degrees) and four possible directions of reflections (horizontal, vertical, left diagonal and right diagonal axis). As a result, there are only three possible values of n (1, 2 and 4) for both the groups *cn* and *dn*. This means that we can get three symmetry groups from the *cyclic* group and three symmetry groups from the *dihedral* group, namely: *c1*, *c2*, *c4*, *d1*, *d2* and *d4*. Note that *c1* is a notation for designs which has no symmetry at all-neither reflection nor rotation; *d1* is the notation for designs which have bilateral, but no other symmetry. The schematic illustrations of classifying the *cyclic* and *dihedral* groups are presented in figure 3.12. The most Lao motifs are big; they are either symmetric or asymmetric. However, all the big motifs found on the samples are classified into the same category named identity motif where the samples from this category takes 6.22% of the analysis, we would see the analysis result in table 3.6 and figure 3.13.

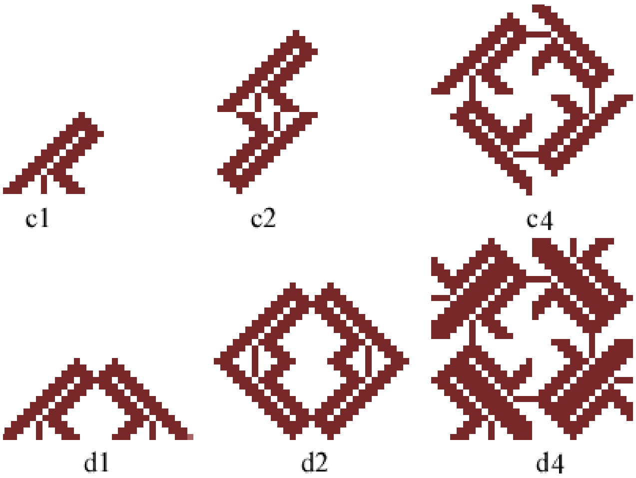


Figure 3.12
Schematic illustrations of the *cyclic* group and *dihedral* groups for generating identity motifs

3.2.4 Analysis Result

The analysis was classified into three groups. The first group is a group of big motifs. The second group is a group of Frieze patterns. The last group is a group of wallpaper patterns. Table 3.6 presents the amount and Percentage of the motif, symmetry group's name of Frieze pattern and wallpaper pattern. The number of patterns in tables 3.6 is different from the number of textile samples shows in table 3.1 due to Lao textiles often decorated with many patterns, especially on shawls. For instance,

No.	Symmetry group	Amount	Percentage
1	Identity motif	74	6.22 %
2	FG: Hop	95	7.98 %
3	FG: Jump	166	13.95 %
4	FG: Sidle	173	14.54 %
5	FG: Spinning Hop	19	1.60 %
6	FG: Sipinning Sidle	2	0.17 %
7	FG: Spinning Jump	419	35.21 %
8	WG: cmm	118	9.92 %
9	WG: pm(h)	1	0.08 %
10	WG: pm(v)	1	0.08 %
11	WG: pmm	121	10.17 %
12	WG: p1	1	0.08 %
Total		1190	100 %

Table 3.6
Identity motif and symmetry groups from textile samples.

in some shawls contain up to seven various patterns, ordered and/or random arrangement between small and medium patterns while a large pattern or a big motif was often designed in the central area of the shawls. The bar chart in figure 3.13 clearly depicts that the Frieze patterns are the most frequently found on Lao textiles, they are in the first three of the range while the *Spinning Jump* group is the most used which takes 35.21% of the samples. The *Sidle* group and *Jump* group are another two common used, because these two groups have similarly symmetric characteristics, so we got similar numbers, 14.54% for the *Sidle* group and 13.95% for the *Jump* group. According to traditional hand weaving, if a pattern is applied vertical reflection and repetitive display in horizontal direction, the symmetry of the pattern is the *Sidle* group, but if the pattern is applied horizontal reflection and repetitive display in vertical direction, symmetry of the pattern is the *Jump* group. Thus, the *Jump* group was often found on narrow shawls and skirt hems. In contrast, the *Sidle* group was often found on the large shawls. The design style on Lao textiles is not only a combination of patterns in different sizes, but it is a combination of different symmetry groups as well. As a result, there is another symmetry groups were found among the Frieze patterns, particularly the *Hop* group. The strange appearance of Lao motifs and the simple of the *Hop* group produce interesting patterns on the textiles; this was proved by the number showed on the chart. Simultaneously, the *pmm* group and the *cmm* group were the most common found among five symmetry groups of wallpaper patterns on Lao textiles. These two groups were often applied for small and medium motifs, they were often found on shawls and skirt hems.

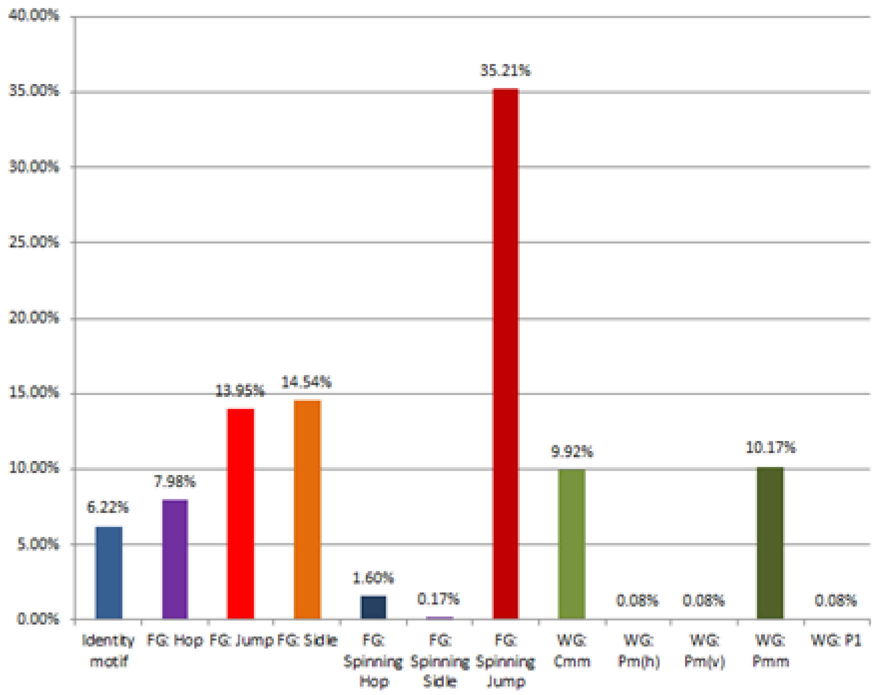


Figure 3.13
Symmetry groups and frequency found on the samples illustrated in percentage.

Nowadays, design style of Lao textiles is still used traditional motifs even the appearances of some motifs are modified. However, the patterns and the decorating styles are periodically changed, particularly among fashionable textiles. For example, in some periods the Frieze patterns will be more popular patterns than the wallpaper patterns, but in another period the Frieze patterns will be less popular than the wallpaper patterns. Therefore, the statistic of the Frieze patterns and the wallpaper patterns can be changed; it depends on the sources and the period of sample collection. The analysis result pointed out that the symmetry operations are important for motif construction while the Frieze groups and wallpaper groups are equally important to the pattern design. The analysis found many missing wallpaper groups on Lao textiles, so this is a gap to introduce twelve symmetry groups of wallpaper patterns to local weavers in order to support more creative and variety design, but still being Lao identity style. Since, a design software tool is required to facilitate design task and to speed up weaving processes, so in the next section we move to scientific term to present mathematics and algorithms that are necessary for software development.

3.3 Mathematics and Algorithms for Digitizing

Generally, a structure of woven textile is created by interlacement of two sets of threads: set of vertical threads called warps and another set of horizontal threads called wefts, regard to this characteristic we represent the information on weaving structure by a binary matrix. In weaving context, there are many ways to form a pattern on a fabric, such as warp-faced patterning and weft-faced patterning. However, our research focuses on traditional Lao textile which is form a pattern by weft-faced patterning. Thus, we defines the values of matrix's elements to be true (or number 1) if the interlacement is warp threads under weft threads, the values are false (or number 0) if the interlacement is warp threads over weft threads. Simultaneously, we represent a graphical feature of the weaving structure by a group of binarization squares, the squares interpret intersection points between warps and wefts while the color of squares depends on the interlacement, if warp threads over weft threads then the color is warp's color, and otherwise the color is weft's color. Moreover, the woven textile has a restriction on rows and columns, every single row and every single column must contain at least one intersection point, this means each row and each column of a binary matrix must have at least one true element. To represent a woven textile in mathematics we define:

M_{mXn} is a binary matrix of a woven textile, m is number of rows and n is number of columns.

m_{iXj} is a matrix element, i is a row index and j is a column index.

The values of matrix's elements are:

$$m_{i,j} = \begin{cases} 0, if\ color\ of\ square\ (i,j)\ is\ warp's\ color \\ 1, if\ color\ of\ square\ (i,j)\ is\ weft's\ color \end{cases} \qquad (3.1)$$

An example of mathematical representation of a woven motif presented in equation (2) and its corresponding graphical feature is presented in figure 3.24. To form a figure of the motif, matrix M contains only binary data to indicate the flow of weft threads under or over warp threads. The matrix M has 17 rows and 13 columns, this means its corresponding motif consists of 17 wefts flows and 13 warps. In this example, the red is a color of wefts while white is a color of warps.

$$M = \begin{bmatrix} 0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,1\,0\,0\,1\,0\,0\,1\,0\,0\,0 \\ 0\,0\,0\,1\,1\,0\,1\,0\,1\,1\,0\,0\,0 \\ 0\,0\,0\,1\,1\,1\,0\,1\,1\,1\,0\,0\,0 \\ 1\,0\,0\,1\,1\,0\,1\,0\,1\,1\,0\,0\,1 \\ 1\,1\,0\,1\,0\,1\,1\,1\,0\,1\,0\,1\,1 \\ 1\,1\,1\,0\,1\,1\,0\,1\,1\,0\,1\,1\,1 \\ 1\,1\,0\,1\,0\,1\,1\,1\,0\,1\,0\,1\,1 \\ 1\,0\,0\,1\,1\,0\,1\,0\,1\,1\,0\,0\,1 \\ 0\,0\,0\,1\,1\,1\,0\,1\,1\,1\,0\,0\,0 \\ 0\,0\,0\,1\,1\,0\,1\,0\,1\,1\,0\,0\,0 \\ 0\,0\,0\,1\,0\,0\,1\,0\,0\,1\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0\,1\,0\,0\,0\,0\,0\,0 \end{bmatrix} \qquad (3.2)$$

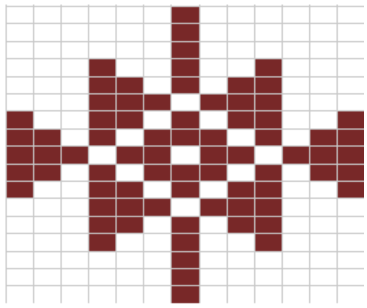


Figure 3.14
A graphical feature of woven motif.

Due to two main processes of weaving are design and drafting, so we investigated methods to satisfy these two purposes. Traditionally, weavers design their woven pattern on point papers, the point paper provides freely design area, a number of columns of the complete pattern on the paper will indicate number of warps needed to be set up on the loom while a number of rows of the pattern will indicate how many weft flows needed to weave a pattern. As a result, our investigated methods for constructing digital motifs, patterns and textiles are based on binary matrices construction and binary matrices operations. In design task we define a binary matrix called canvas to serve as a point paper, this means motifs and patterns are created and displayed on the canvas. We divide the digitizing methods into two parts, since traditional Lao textiles contain variety of motifs, it is necessary to separate digitizing motifs apart from digitizing patterns and textiles. In the first part we will introduce methods for digitizing motifs, after that in another part we will present methods for generating patterns and digital weave-drafts. The following section will explain detail of each method.

3.3.1 Digitizing Methods for Generating Motifs

In cultural context, we categorized motifs into 5 groups based on types of mythical creatures, plants and animals, but in scientific aspect to construct digital motifs we separate motifs into two types based on the analysis of their structure and their characteristics, the first type called lined motif and the second type called single motif. We called the first type is lined motif because it is a path or a line of repetitive display an atomic icon on diagonal, horizontal or vertical direction. The atomic icon is a unique segment of the lined motif. Since traditional Lao design style always uses two different kinds of motifs, the complementary and the supplementary motifs while the lined motifs are often used as supplementary elements to create complementary motifs. The various used line motifs often found on the *Naga*, the *diamond Naga head* motifs and *zigzag lined* patterns. In design context, the composite motifs and *zigzag lined* patterns are freely in design; the combination of supplementary motifs is based on designers' imagination. Therefore, the method for constructing individual lined motifs will facilitate the design task to be more flexible and to be more specific to traditional Lao style. The second type we called a single motif because it does not contain another motif as its component. Many considered single motifs are taken from five groups of traditional motifs by eliminating every single supplementary symbol from complementary motifs. After analysis the traditional Lao textile, we found many single motifs which become a rich source to modify and/or to redesign new motifs or new patterns. The same idea to the lined motif, in design context the single motifs are often used as supplementary symbols while the combination is open design. Thus, our investigated methods for constructing single motifs concentrate on flexibility in design and specific to traditional Lao style.

From the study we found many common lined and single motifs on many types of textiles, in some motifs their appearances look the same among textiles, but the appearance of some motifs are slightly changed from textile to textile. As a result, the predefined motifs are taken into account in our research; we constructed predefined lined and single motifs that are common motifs from five groups of traditional motifs. The list of predefined motifs will support design process to be faster and easier. In addition, the predefined motifs are not only to support design task, but they are also considered to support cultural preservation, the digital data models of our predefined motifs will be stored in online database for online digital archiving. There were more than 50 motifs from *Naga group* were constructed, because *Naga* motifs were identity symbols of traditional Lao textile, they were designed in many actions and given different names, such as *mating Naga*, *twisted tail Naga* and so on. Thus, we classified the predefined *Naga* motifs into subgroup and named by their corresponding actions. Moreover, there were more than 10 motifs from *Siho*, *Giant* and *Bird* groups were constructed, as well as many common lined motifs were created. The predefined motifs were created in standard file formats, in WIF (Weaving Information File) format and image file formats, such as: .bmp, jpg .tiff and so on. In the following sections we are going to present mathematical concepts and scientific methods for constructing both two types of motifs, we will start by mathematics of geometric principles for constructing lined motifs, and then introduce image processing techniques for extracting single motifs from photographs. For the detail of digital file formats will be presented in section 3.3.2, and the detail of online digital archiving will be explained in detail in the next chapter.

3.3.1.1 Mathematics and algorithms for Generating Lined Motifs

The mathematics and algorithms for generating lined motifs are based on characteristics of Lao motifs. We are also inspired from the studies on the composite patterns in ancient Eurasian Ornamental arts [70], and in ancient Crete and Urartu [71]. Therefore, each motif' layer is able to be separately created. The nature of woven textile has some restrictions to generate traditional Lao lined motifs, a path of atomic icon (unique segment) can be generated only in four possible directions, namely a path with slope equals to 1, slope equals to -1, slope equals to 0 and a path with slope equals to infinity. The path is generated by defining a few steps, first is to define begin and end points in order to determine path's length, then defines a desired icon (unique segment) that need to be displayed on the path. A frequency of the icon appear on the path depends on a quotient of a division between path length and icon's size. If we generate a vertical path, the number of displayed atomic icon is a quotient of a division between path length and icon's high, but if we generate a horizontal or diagonal path, the number of displayed icon is a quotient of a division between path length and icon's width. The equation (3.3) and (3.4) are mathematical equations to compute the number of repetitive icon (unique segment) in each case while algorithm 3.1 presents constructing's steps for attaching atomic icon to a path, in the algorithm we will see that generating a lined motif is always related to positions on the canvas, because we provide a canvas as a design area where all designed motif must be displayed on the canvas. The mathematical notations and equations for constructing a lined motif are presented below, we denote

I_h is a icon's height
I_w is a icon's width
P_l is a path's length
N_{ic} is a number of icon appears on the path

Equation for computing number of atomic icon appeared on a vertical path is:

$$N_{ic} = \frac{P_l}{I_h} \qquad (3.3)$$

Equation for computing number of atomic icon appeared on a horizontal or diagonal path of atomic icon is:

$$N_{ic} = \frac{P_l}{I_w} \qquad (3.4)$$

$$where\ P_l \geq I_h, P_l \geq I_w\ , P_l > 0, I_h > 0, P_l\ , I_h, I_w, N_{ic}\ \in N$$

Algorithms 3.1: attach atomic icon to a path

To generate any lined motif or to create a path of atomic icon (unique segment) do following:

1. Define an atomic icon on the canvas
2. Define a start point on the canvas
3. Define another point to determine path type

4. Copy the icon to the start point of the path
5. Distribute the atomic icon along to the path by checking path type with following conditions:

$if\ slope\ = 1$ then generate right diagonal path

$$N_{ic} = (\frac{P_l}{I_h})$$

$if\ slope\ = -1$ then generate left diagonal path

$$N_{ic} = (\frac{P_l}{I_h})$$

$if\ slope\ =\ 0$ then generate vertical path

$$N_{ic} = (\frac{P_l}{I_h})$$

$if\ slope\ =\ infinity$ then generate horizontal path

$$N_{ic} = (\frac{P_l}{I_w})$$

However, lined motifs are just lines of repetitive icon if only using this type is not enough to create interesting patterns particularly to create patterns of Lao textiles. We need single motifs which are another type of Lao motifs; the motifs of this type can be asymmetrical or symmetrical, so symmetry operations are required in order to provide more creative motifs, especially to create motifs of cyclic and dihedral groups. As a result, in the following section we will present scientific methods for generating single motif by using geometric principles of symmetry.

3.3.1.2 Symmetry Operations for Generating Single Motifs

To generate symmetrical motifs, the numbers of n-fold rotation and the numbers of reflect direction are also limited on woven textile, only three available degrees to rotate a motif on the canvas, namely: 90, 180 and 270 degrees. Simultaneously, there are only four available directions to flip a motif on the canvas, such as: flip around a vertical line, a horizontal line, a left diagonal line and a right diagonal line. Note that, we define the direction of rotation and flipping in clockwise direction. To support creative work, we divided symmetry operations in two groups; the first group is to provide four basic symmetry operations, such as rotation and reflection. Another group contains operations for creating symmetry motifs of cyclic and dihedral groups. Mathematical notations and equations for the first group are listed below, we denote

r_{90} as an operation to rotate a segment in 90 degree
r_{180} as an operation to rotate a segment in 180 degree
r_{270} as an operation to rotate a segment in 270 degree
f_v as an operation to flip a segment around vertical line
f_h as an operation to flip a segment around horizontal line
f_{ld} as an operation to flip a segment around left diagonal line
f_{rd} as an operation to flip a segment around right diagonal line

A given segment S_{wXh} is a binary matrix, and its element $s_{i,j}$, where $\forall i \in [0, w-1], \forall j \in [0, h-1]$.

C_{rXc} is a binary matrix of a canvas, and its element $c_{p,q}$, where $\forall p \in [0, p-1], \forall q \in [0, q-1]$.

An equation to apply r_{90} rotation operation to the matrix S_{wXh} at the rotated point $R(x, y)$ on the canvas is:

$$(r_{90})S_{wXh} \Rightarrow c_{(n-1)+x,(m-1+h)+y} = s_{m-1,h-n} \quad \forall m \in [w, 1], \forall n \in [h, 1] \tag{3.5}$$

An equation to apply r_{180} rotation operation to the matrix S_{wXh} at the rotated point $R(x, y)$ on the canvas is:

$$(r_{180})S_{wXh} \Rightarrow c_{(m-1-w)+x,(n-1+h)+y} = s_{w-n,h-m} \quad \forall m \in [w, 1], \forall n \in [h, 1] \tag{3.6}$$

An equation to apply r_{270} rotation operation to the matrix S_{wXh} at the rotated point $R(x, y)$ on the canvas is:

$$(r_{270})S_{wXh} \Rightarrow c_{(n-1-h)+x,[(m-1)-(w-h)+y} = s_{w-m,n-1} \tag{3.7}$$
$$where\ \forall m \in [w, 1], \forall n \in [h, 1]$$

An equation to apply f_v flipping operation to the matrix S_{wXh} at a flipped point $F(x, y)$ on the canvas is:

$$(f_v)S_{wXh} \Rightarrow c_{(m-1)+x,(n-1+h)+y} = s_{m-1,h-n} \quad \forall m \in [w, 1], \forall n \in [h, 1] \tag{3.8}$$

An equation to apply f_h flipping operation to the matrix S_{wXh} at a flipped point $F(x, y)$ on the canvas is:

$$(f_h)S_{wXh} \Rightarrow c_{(m-1-w)+x,(n-1)+y} = s_{w-m,n-1} \quad \forall m \in [w, 1], \forall n \in [h, 1] \tag{3.9}$$

An equation to apply f_{ld} flipping operation to the matrix S_{wXh} at a flipped point $F(x, y)$ on the canvas is:

$$(f_{ld})S_{wXh} \Rightarrow c_{m+x,n+y} = s_{w-1-m,h-1-n} \tag{3.10}$$

$$where\ m \leq w-n, \forall m \in [0, w-1], \forall n \in [0, h-1]$$

An equation to apply f_{rd} flipping operation to the matrix S_{wXh} at a flipped point $F(x, y)$ on the canvas is:

$$(f_{rd})S_{wXh} \Rightarrow c_{m+x,n+y} = s_{n,m} \tag{3.11}$$

$$where\ m \geq n, \qquad \forall m \in [0, w-1], \forall n \in [0, h-1]$$

The translation and rotation operations play import role for generating motifs of the *cyclic* and *dihedral* groups. As explained before, the motifs of the *cyclic* group apply only rotation while the motifs of the *dihedral* group apply both rotation and reflection. Totally, we have five symmetry operations for generating motifs of them, two operations for the *cyclic* group and three operations for the *dihedral* group. The detail of their mathematical notations and equations are listed below, we denote

A given segment S_{wXh} is a binary matrix, and its element $s_{i,j}$, where $\forall i \in [0, w-1], \forall j \in [0, h-1],\ w \geq 1, h \geq 1$.

C_{rXc} is a binary matrix of a canvas, and its element $c_{p,q}$, where $\forall p \in [0, p-1], \forall q \in [0, q-1]$.

T_{2*wXh} is a binary matrix for translation, and its element $t_{i,j}$, where $\forall i \in [0,2*w-1], \forall j \in [0, h-1]$.

The motif of the *c2* group: contains 2-folds rotation; it means that a motif is created by copying a given segment and rotating in 180 degree to form a motif. We define an additional binary matrix T_{2*wXh}, it is used to store values of the rotation before forming a complete motif. $t_{i,j}$ is its element, where $\forall i \in [0,2*w-1], \forall j \in [0, h-1]$. There are three steps to generate the motif of the *c2* group as follows.

Step1: Rotates *S* in 180 degrees, we get first half of the motif

$$(r_{180})S_{wXh} \Rightarrow c_{(m-1-w)+x,(n-1+h)+y} = s_{w-n,h-m} \quad \forall m \in [w, 1], \forall n \in [h, 1] \qquad (3.12)$$

Step2: Copy rotation's result from the canvas to T matrix

$$t_{i,j} = c_{i+x-w,j+y} \quad \forall i \in [0, 2*w-1], \forall j \in [0, h-1] \qquad (3.13)$$

Step3: Paste value of the T matrix to the canvas, we get second half of the motif

$$c_{((i-1)+x+w,(j-1+h)+y} = t_{i-i,h-j} \quad \forall i \in [2*w, 1], \forall j \in [h, 1] \qquad (3.14)$$

The motif of the *c4* group: contains 4-folds rotation, the motif is created by copying a given segment and rotating the segment three times in 90 degrees. A size of motif must be double size of a given segment. There are three steps to generate the motif of the *c4* group as follows.

Step1: Copy and rotates *S* in 90 degrees, we get second quarter of the motif

$$(r_{90})S_{wXh} \Rightarrow c_{(n-1)+x,(m-1+h)+y} = s_{m-1,h-n} \quad \forall m \in [w, 1], \forall n \in [h, 1] \qquad (3.15)$$

Step2: Copy and rotates *S* in 180 degrees, we get third quarter of the motif

$$(r_{180})S_{wXh} \Rightarrow c_{(m-1-w)+x,(n-1+h)+y} = s_{w-n,h-m} \quad \forall m \in [w, 1], \forall n \in [h, 1] \qquad (3.16)$$

Step3: Copy and rotates *S* in 270 degrees, we get forth quarter of the motif

$$(r_{270})S_{wXh} \Rightarrow c_{(n-1-h)+x,[(m-1)-(w-h)+y} = s_{w-m,n-1} \qquad (3.17)$$

The motif of the *d1* group: contains a vertical reflection no rotation. We denote *d1* is an operation to create a motif of the *d1* group. Its mathematical equation is exactly the same as the equation to operate vertical reflection to the matrix S_{wXh} in equation 3.8.

The motif of the *d2* group: contains 2-folds reflection and 2-folds rotation. We define an additional binary matrix $V_{wX2*h-1}$ to store reflection's result, $v_{i,j}$ is its element, where $\forall i \in [0,2*w-1], \forall j \in [0,2*h-2]$. There are three steps to generate the motif of the *d2* group as follows.

Step 1: apply vertical reflection to *S* then we get first half of the motif. Its equation is exactly the same as applying vertical reflection to *S* in equation 3.8

Step 2: Copy values of the first half's segment from the canvas to matrix

$$v_{i,j} = c_{i+x,j+y} \quad \forall i \in [0, w-1], \forall j \in [0,2*h-2] \tag{3.18}$$

Step 3: Paste the value of the V matrix to the canvas, and then we get second half of the motif

$$c_{((i-w)+x,(j-1)+y} = v_{w-i,j-1} \quad \forall i \in [w,1], \forall j \in [2*h-1,1] \tag{3.19}$$

The motif of the *d4* group: contains 4-folds reflection and 4-folds rotation. There are three steps to generate the motif of the *d2* group as follows.

Step 1: apply (right) diagonal reflection to *S* then we get a first quarter of the motif, its mathematical equation is exactly the same as the equation to apply (right) diagonal reflection to *S* matrix in equation 3.11.

Step 2: Rotates the first quarter in 90 degrees, we get a second quarter of the motif

$$c_{(j-1)+x,(i-2+h)+y} = c_{(i-1)+x,(h-j)+y} \quad \forall i \in [w,1], \forall j \in [h,1] \tag{3.20}$$

Step 3: Rotates the first quarter in 180 degrees, we get a second quarter of the motif

$$c_{((i-w)+x,(j-2+h)+y} = c_{w-i+x,h-j+y} \quad \forall i \in [w,1], \forall j \in [h,1] \tag{3.21}$$

Step 4: Rotates the first quarter in 270 degrees, we get a forth quarter of the motif

$$c_{((j-h)+x,(i-1)-(w-h)+y} = c_{(w-i)+x,(j-1)+y} \quad \forall i \in [w,1], \forall j \in [h,1] \tag{3.22}$$

The introduction above explains methods to generate symmetrical motifs by defining characteristics of symmetry. The binary data of a motif's matrix is given by corresponding symmetry operation. This method gives a room to designers to create their complete motifs by themselves. The constructing processes directly works on the canvas which is easy to modify and to visualize the output. This method provides various possible appearances of a motif depending on which operation is assigned; the method is suitable to create flexible motifs and to get various outputs. However, a unique segment of motif is required before applying any operation, if a desired motif is complicated and quite big, this will take times to complete the task. Regarding to this issue, we investigated one more technique to extract a motif's segment or a whole part of motif from photographs or images from any digital devices, this method makes sure the constructing process do not start from beginning. We are based on the common digital representations of woven pattern that each pixel of an image is interpreted as a thread on a woven pattern, we also regard to the binary property of woven pattern. Thus, image processing is a qualified technique to fulfill our goal. The detail of all needed techniques to process a given image in order to get a segment or a motif we are going to explain in the next section.

3.3.1.3 Image Processing Techniques for Extracting Single Motifs

We have explained in chapter 2 that motifs and patterns of our research are for weft-face patterning which means their figures on textiles formed by floating weft threads over warp threads. Regarding this property, extracting digital motifs in this section is a method to extract floating data of weft threads from images. Because a binary matrix is used to store weaving information of a motif, we particularly need binary data from a given image. We based on a relationship between color and weave structures that expressed in [43][41][5][68][36]. Therefore, we use image processing techniques to convert color images to binary images. The binary images can be interpreted as graphical representation of the binary matrices, where a black pixel indicates "true value" or "weft over warp" and a white pixel indicates "false value" or "weft underneath warp". However, extracting Lao motifs from images is not easy task due to a complexity of motif's structures and numerous pixels' colors on the images. The involved processes for extracting are contrast enhancement, binarization, noise removal and edge adjustment. We divide the processes into three main steps. The first step is a process to convert a color image to a grayscale image, then the second step is to convert the grayscale image to a binary image, and the final step is a process to operate the binary image in order to get desired digitized motif. In each step the processes are repeatedly performed until the desired results are achieved. The flowchart for motif extraction and digitization is illustrated in figure 3.15. We will explain image processing techniques used in each step by starting from the techniques used in the first step.

Step1: Contrast Enhancement

The aim of this step is to get grayscale images from input photos. The contrast enhancement will highlight the motif by changing the contrast between th**e** motif and its background. As the motif's color is insignificant, the motif is converted to grayscale image for contrast enhancement.

Step2: Image Binarization

This step works on grayscale image 8bit pixel where totally there are 256 colors, but at the end output will be only binary image. Black pixel in grayscale value for 8 bits/pixel indexed image its value will be 0. White pixel in grayscale value for 8 bits/pixel indexed image its value will be 255. There are many existing algorithms for image binarization, such as: thresholding, Bayer dithering and so on. However, the image binarization in this step we use the thresholding techniques. There are four possible thresholding methods to obtain binary images namely *threshold below, threshold above, threshold inside* and *threshold outside* [12] [45]. The thresholding operation chooses some of the pixels as the foreground pixels that make up the objects of interest and the rest as background pixels. A certain gray-tone value

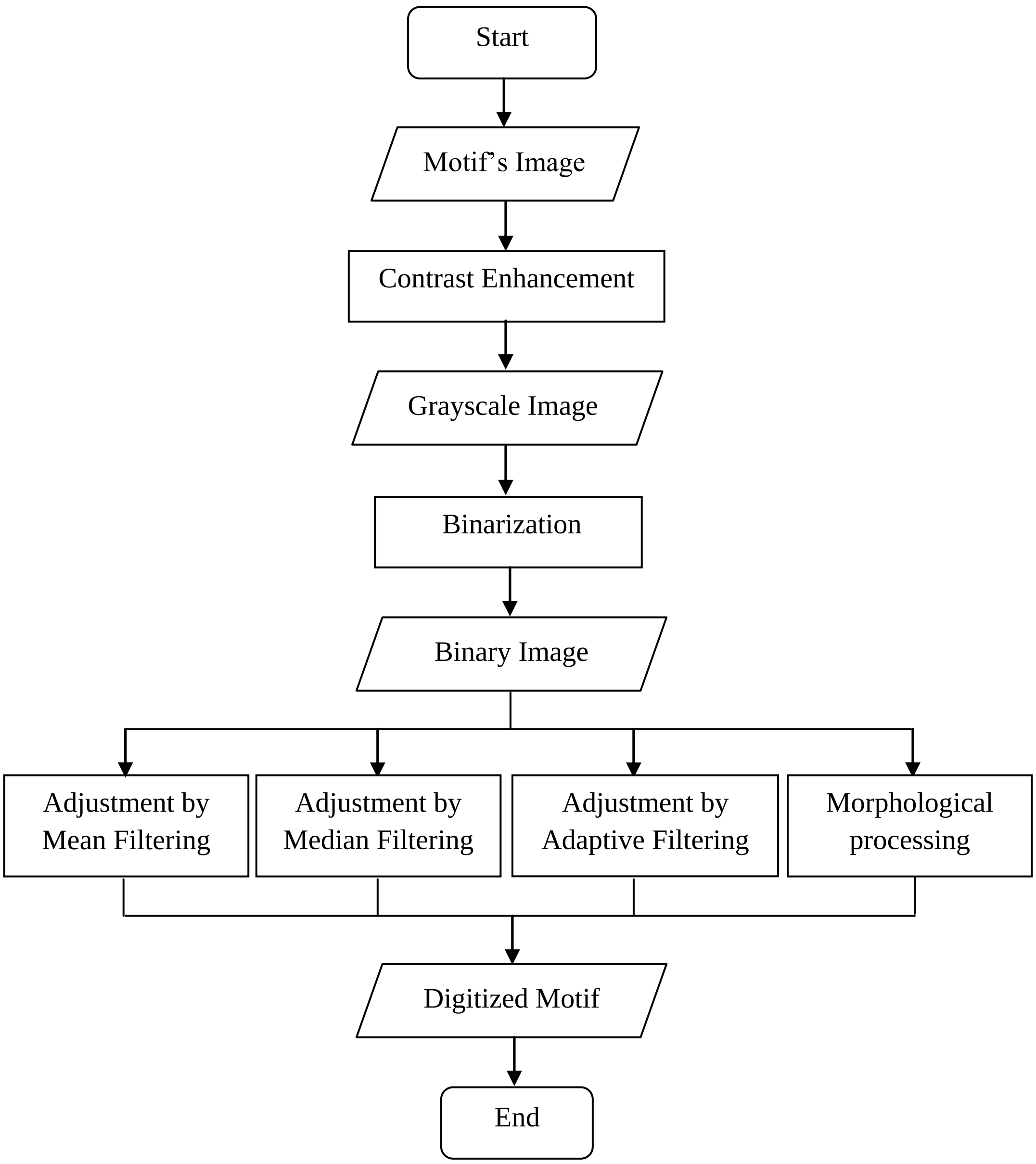


Figure 3.15
A flowchart for extracting and digitizing motif by image processing techniques

can be chosen as threshold values that separate the pixels in the groups. We suppose a single threshold value t is chosen, the *threshold above* will operate pixels by assigning all pixels whose gray-tone values are greater than or equal to t become foreground pixels and all the rest become background. The *threshold below* makes the pixels with values less than or equal to t the foreground. The *threshold inside* method required two given thresholds, a lower threshold and an upper threshold. This method selects pixels whose values are between the two as foreground. In contrast, the operation by *threshold outside* is the opposite of the operation by *threshold inside*. The critical part on thresholding is choosing the appropriate threshold level which will give a shape of binary image close to original structure of the woven motifs.

Step3: Noise Removal and Edge Adjustment

Because the input is a multi-color photo of woven motif that contains complicated structure and complicated decoration, it is impossible to get precise shape of digitized motif by just converting a grayscale image to a binary image from step number 2 (details of the experiment explain in section 5.1.4 in chapter 5, page 106). After binarization processing, the binary images still contain noise and inappropriate segments on the images. Therefore, the morphological operations and filtering techniques are necessary tools to remove noise from the binary images. The studies on noise removal and enhancement of binary image in [56][55] are inspired us to investigate three different filters: mean, median and adaptive filters for noise removal and edge adjustment. The mean filter is used to smooth sharp features and thus in the reduction of intensity disparity of pixels whose intensities are must above or below those of the neighbors. The median filter can preserves or reconstruct edge and other image details while removing noise. The adaptive filter is commonly used in image processing to enhance or restore data by removing noise without significantly blurring the structures in the image. Normally, it is used in cases where the noise has become significant. Based on properties of those three filters, we will compare which filter provides better results. We also investigate on four basic morphological operations namely dilation, erosion, opening and closing. It is necessary to understand mathematical concept of morphology in order to perform a suitable technique for solving specific problems. Thus, we will explain mathematical concept of morphology and its related operations as follows.

Morphology and Structuring Elements

Mathematical Morphology is a theory which provides a number of useful tools for image analysis. It is an approach to analyze images by based on the assumption that an image consists of structures which may be handled by set theory. Thus the fundamental objects are sets that consist of pixels in an image. The operations of mathematical morphology is originally defined as set operations and showed to be useful for processing sets of 2D points [12] [45] [51]. In this research, we use the operations of morphology to process binary image.

The structuring element represents a shape; it can be of any size and have arbitrary structure that can be represented by a binary image. However, there are a number of common structuring elements such as a rectangle of specified dimensions or a circular region of specified diameter [9]. The purpose of the structuring elements is to act as probes of the binary image. One pixel of the structuring element is denoted as its origin; this is often the central pixel of a symmetric structuring element. Using the origin as a reference point, translations of the structuring element can be placed anywhere on the image and can be used to either enlarge a region by that shape or to check whether or not the shape fit inside a region. The basic morphological operations used in this research are explained below:

Dilation operation: Dilation allows objects to expand, thus potentially filling in small holes and connecting disjoint objects. The dilation process is performed by laying the structuring element S on the image B and sliding it across the image in a manner similar to convolution. The difference is in the operation performed. It is best described in a sequence of steps:

1. If the origin of the structuring element coincides with a 'white' pixel in the image, there is no change; move to the next pixel.
2. If the origin of the structuring element coincides with a 'black' pixel in the image, make black all pixels from image covered by structuring element.

The structuring element S is swept over the image. Each time the origin of the structuring element touches a binary 1-pixel, the entire translated structuring element shape is ORed to the output image, which has been initialized to all zeros. Note that with a dilation operation, all the 'black' pixels in the original image will be retained, any boundaries will be expanded, and small holes will be filled. Equation (3.23) illustrates the dilation of binary image B by structuring element S.

$$B \oplus S = \bigcup_{b \in B} S_b \tag{3.23}$$

Erosion operation: Erosion shrinks objects by etching away (eroding) their boundaries. The erosion process is similar to dilation, but we turn pixels to 'white', not 'black'. As before, slide the structuring element across the image and then follow these steps:

1. If the origin of the structuring element coincides with a 'white' pixel in the image, there is no change; move to the next pixel.
2. If the origin of the structuring element coincides with a 'black' pixel in the image, and at least one of the 'black' pixels in the structuring element falls over a white pixel in the image, then change the 'black' pixel in the image (corresponding to the position on which the center of the structuring element falls) from 'black' to a 'white'.

The erosion operation also sweeps the structuring element over the entire image. At each position where every 1-pixel of the structuring element covers a 1-pixel of the binary image, the binary image pixel corresponding to the origin of the structuring element is ORed to the output image. Equation (3.24) illustrates the erosion of binary image B by structuring element S.

$$B \ominus S = \{b | b + s \in B \; \forall s \in S\} \qquad (3.24)$$

Opening and closing operation: Opening and closing are morphological filtering, Opening consists of erosion followed by dilation and can be used to eliminate all pixels in regions that are too small to contain the structuring element. Equation (3.25) illustrates the opening of binary image B by structuring element S.

$$B \circ S = (B \ominus S) \oplus S \qquad (3.25)$$

Closing consists of dilation followed by erosion and can be used to fill in holes and small gaps. The order of operation is important. Closing and opening will generate different results even though both consist of erosion and dilation. These operations can be customized for an application by the proper selection of the structuring element, which determines exactly how the objects will be dilated or eroded. Equation (3.26) illustrates the opening of binary image B by structuring element S.

$$B \bullet S = (B \oplus S) \ominus S \qquad (3.26)$$

Scaling Operation: Nearest Neighbor Interpolation

In terms of image processing, scaling image means to increase or decrease number of pixels to/from the image while the color of scaled image is performed by color interpolation. There are many existing color interpolation algorithms, such as: cubic color interpolation, linear color interpolation and nearest neighbor interpolation [82] [72]. Each method has specific properties and performs to specific purpose. In the context of woven design, image scaling is very sensitive, the color of pixels indicates status of interlacement between wefts and warps, thus the nearest neighbor interpolation is a suitable method for scaling images. By properties of nearest neighbor interpolation, this method makes sure there is no new color added to the images and it can provide the same shape of image after scaling.

Nearest neighbor is the simplest and fastest implementation of image scaling technique. Its scaling algorithm only needs horizontal and vertical ratios between the original image and the (to be) scales image. We assume $w1$ and $h1$ are the width and height of an image, whereas $w2$ and $h2$ are the width and height when enlarged (or shrunk). Equation 3.27 illustrate a ratio calculation for both horizontal (r_h) and vertical (r_v).

$$\left.\begin{aligned} r_h &= \frac{w_1}{w_2} \\ r_v &= \frac{h_1}{h_2} \end{aligned}\right\} \; w_2, h_2 \neq 0 \qquad (3.27)$$

The experiment results and drawbacks on image processing techniques for digitizing motif explain in chapter 5. In the following section we will move forward to the section of digitizing pattern.

3.3.2 Mathematics and Algorithms for Generating Patterns

We investigated two scientific methods for generating patterns based on the requirement on a variety of pattern styles and the flexibility on pattern modification. Our first method considered on geometric principles, it focused on a pattern generating task by following characteristics of symmetry in seven Frieze groups and twelve wallpaper groups. Simultaneously, the second investigated method concentrated basically on a pattern modification task. In this method we presented a mathematic equation for pattern construction that simulated a collaborative work of weaving components on hand-weaving floor-loom. The algorithms for pattern generating based on symmetry groups will be presented first, after that the detail of the second method will be explained afterward.

3.3.2.1 Generating Patterns by Symmetry Groups

The characteristics of symmetry groups in Frieze patterns and wallpaper patterns are various from group to group, so to implement geometric principles of each group it is necessary to provide efficient instructions. Therefore, we created algorithms for pattern generation; the procedures of algorithms follow geometric principles of symmetry groups. We start from seven algorithms for creating Frieze patterns (algorithm 3.2 to algorithm 3.8) and then sixteen algorithms for creating wallpaper patterns (algorithm 3.9 – algorithm 3.24). The general concept of the algorithms is that first creates a function to get a motif of a pattern and then create a function to generate the pattern by according to geometric structure of the pattern. We define necessary notations for pattern generation as follows:

s	is a given segment on the canvas
s_h	is segment's height
s_w	is segment's width
m	is a generated motif from a function
m_h	is motif's height
m_w	is smotif's width
$addP(addP.x, addP.y)$	is added point on the canvas
$sP(sP.x, sP.y)$	is start point to display a pattern on the canvas
no_repeat	*i*s number of repeat motif on the generated pattern
x_repeat	is number of repeat motif in horizontal direction
y_repeat	is number of repeat motif in vertical direction
d	is a given distance for glide reflection

Algorithm 3.2: generate a frieze pattern of *Hop* group
The algorithm copies a given segment (in this group a segment is a motif) and then it repetitive generates the segment in one direction by number of repeat no_repeat and add point adP. Finally, the pattern is achieved regard to no_repeat and $addP$. Steps of the algorithm are:

1. Define a function $paste(s, addP)$ to copy and paste the segment to the canvas
2. Define a function $Hop(no\_repeat)$ to generate the pattern.

```
Hop(no_repeat)
      For i=0 to no_repeat
            addP.x = sP.x;
            addP.y = sP.y + i*s_h
            paste(s,addP)
      End for
```

Algorithm 3.3: generate a frieze pattern of *Step* group

Its motif contains horizontal glide reflection, the algorithm copies a given segment to flip in horizontal direction after that translate an output in horizontal direction as well. Finally, the pattern is achieved regard to no_repeat, $addP$ and a given distance d. Steps of the algorithm as follows:

1. Define a function $Copy\_hGlideReflection(\&m, \&m_w, \&m_h)$ to copy and horizontal flipping and translation respectively for getting a motif m and its size m_w, w_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define function $Step\ (no\_repeat)$ to generate a pattern

```
Step(no_repeat)
      For i=0 to no_repeat
            addP.x = sP.x-s_w;
            addP.y = sP.y + i*s_h
            pastetoCanvas(m,m_w,m_h,addP)
      End for
```

Algorithm 3.4: generate a frieze pattern of *Jump* group

The algorithm copies a given segment to flip around horizontal line to form a motif, and then it repetitive displays the motif in one direction by according to a given added point $addP$, a given number of repeat no_repeat. Finally, the pattern is achieved based on no_repeat and $addP$. Steps of the algorithm are:

1. Define a function $Copy\_hReflection(\&m, \&m_w, \&m_h)$ to copy and horizontal reflect the segment for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define function $Jump(no\_repeat)$ to generate a pattern

```
Jump(no_repeat)
      Copy_hReflection(m,m_w,m_h)
      for  i=0  to no_repeat
            addP.x = sP.x-s_w;
            addP.y = sP.y + i*s_h
            pastetoCanvas(m,m_w,m_h,addP)
      end for
```

Algorithm 3.5: generate a frieze pattern of *Sidle* group

The algorithm copies a given segment to flip around vertical line to form a motif, and then repetitive display the motif in one direction by according to a given added point $addP$, a given number of repeat no_repeat. Finally, the pattern is achieved based on no_repeat and $addP$. Steps of the algorithm are:

1. Define a function $Copy\_vReflection(\&m, \&m_w, \&m_h)$ to copy and vertical reflect the segment for generating a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define function $Sidle(no\_repeat)$ to generate a pattern

```
Sidle(no_repeat)
      Copy_vReflection(m,mw,mh)
      for  i=0  to no_repeat
            addP.x = sP.x;
            addP.y = sP.y + i*(sh-1)
            pastetoCanvas(m,mw,mh,addP)
      end for
```

Algorithm 3.6: generate a frieze pattern of *Spinning Hop* group

The algorithm copies a given segment to rotate in 180 degree to form a motif, and then repetitive display the motif in one direction by according to a given added point $addP$, a given number of repeat no_repeat and a given distance d of glide translation. Finally, the pattern is achieved based on $no\_repeat, addP$ and d. Steps of the algorithm are:

1. Define a function $Copy\_Rotate180\_Translate(\&m, \&m_w, \&m_h, d)$ to copy and rotate the segment in 180 degree, after that translate an output by d distance for generating a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define function $Spinning\_Hop(no\_repreat)$ to generate a pattern

```
Spinning_Hop(no_repeat,d)
      Copy_Rotate180_Translate(m,mw,mh,d)
      for  i=0  to no_repeat
            addP.x = sP.x-sw;
            addP.y = sP.y + i*sh
            pastetoCanvas(m,mw,mh,addP)
      end for
```

Algorithm 3.7: generate a frieze pattern of *Spinning Sidle* group

To form a motif the algorithm does two steps, first it copies a given segment to flip around vertical line, after that it copies a result from step1 to rotate in 180 degree and then it apply glide translation from a given distance d. Finally, a frieze pattern is generated by repetitive display the motif in one direction based on a given added point $addP$, a given number of repeat no_repeat and a given distance d of glide translation. Finally, the pattern is achieved based on $no\_repeat, addP$ and d. Steps of the algorithm are:

1. Define a function $vReflection\_Rotate180(\&m, \&m_w, \&m_h, d)$ to copy and vertical reflection of the segment and then rotate the output in 180 degree, after that translate them by d distance, for generating a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define function $Spinning\_Sidle(no\_repeat, d)$ to generate a pattern

```
Spinning_Sidle(no_repeat,d)
      vReflection_Rotate180(m,mw,mh,d)
      for  i=0  to no_repeat
            addP.x = sP.x-sw;
      addP.y = sP.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
```

Algorithm 3.8: generate a frieze pattern of *Spinning Jump* group

To form a motif the algorithm does two-fold rotation and two-fold reflection like *d2* group, actually it is a motif of *d2* group. After that, the motif is repetitive displayed in one direction based on a given added point $addP$, a given number of repeat no_repeat. Finally, the pattern is achieved based on no_repeat and $addP$. Steps of the algorithm are:

1. Define a function $vReflection\_hReflection(\&m, \&m_w, \&m_h)$ to copy and vertical reflection of the segment and then horizontal the output for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif that generated from step1 to the canvas
3. Define function $Spinning\_Jump(no\_repeat)$ to generate a pattern

```
Spinning_Jump(no_repeat)
      vReflection_hReflection(m,mw,mh)
      for  i=0  to no_repeat
            addP.x = sP.x-sw;
            addP.y = sP.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
```

Algorithm 3.9: generate a wallpaper pattern of vertical *cm* group

To get a fundamental parallelogram (one repeat pattern) of the vertical *cm* group, the algorithm performs two steps. First it copies and vertical reflects a segment, and then in the second step it applies vertical glide reflection to an output of the previous step. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction, number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_vReflecion\_Translate(\&m, \&m_w, \&m_h, d)$ to copy and vertical reflect a segment, after that translate an output for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $cm\_v(x\_repeat, y\_repeat)$ to generate a pattern

```
cm_v(x_repeat,y_repeat)
      Copy_vReflection_Translate(m,mw,mh,d)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw) + j*mw
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

Algorithm 3.10: generate a wallpaper pattern of horizontal *cm* group

To get a fundamental parallelogram (one repeat pattern) of the horizontal *cm* group, the algorithm performs two steps, first it copies and horizontal reflects a segment, and then in the second step it applies horizontal glide reflection to an output of the previous step. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction, number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_hReflecion\_Translate(\&m, \&m_w, \&m_h, d)$ to copy and horizontal reflect a segment, after that translate an output for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $cm\_h(x\_repeat, y\_repeat)$ to generate a pattern

```
cm_h(x_repeat,y_repeat)
      Copy_hReflection_Translate(m,mw,mh,d)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw) + j*mw
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

Algorithm 3.11: generate a wallpaper pattern of vertical *pm* group

A motif of vertical *pm* group is created like a motif of the *Sidle* group, but the pattern is generated in two directions by according to a given added point $addP$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction. Finally, the pattern is created by x_repeat, y_repeat and $addP$. Steps of the algorithm are:

1. Define a function $Copy\_vReflection(\&m, \&m_w, \&m_h)$ to copy and vertical reflect a segment s for generating a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif that generated from step1 to the canvas
3. Define function a $pm\_v(x\_repeat, y\_repeat)$ to generate a pattern

```
pm_v(x_repeat,y_repeat)
       Copy_vReflection(m,mw,mh)
       for  i=0  to x_repeat
       for  j=0  to y_repeat
              AddP.x = sP.x + sw*j
              AddP.y = sP.y + i*(mh-1)
              pastetoCanvas(m,mw,mh,addP)
       end for
       end for
```

Algorithm 3.12: generate a wallpaper pattern of horizontal *pm* group

A motif of vertical *pm* group is created like a motif of the *Jump* group, but the pattern is generated in two directions by according to a given added point $addP$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction. Finally, the pattern is created regard to x_repeat, y_repeat and $addP$. Steps of the algorithm are:

1. Define a function $Copy\_hReflection(\&m, \&m_w, \&m_h)$ to copy and horizontal reflect a segment s for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif that generated from step1 to the canvas
3. Define a function $pm\_h(x\_repeat, y\_repeat)$ to generate a pattern

```
Pm_h(x_repeat,y_repeat)
       Copy_hReflection(m,mw,mh)
       for  i=0  to x_repeat
       for  j=0  to y_repeat
              AddP.x = (sP.x-sw) + j*2*sw
              AddP.y = sP.y + i*sh
              pastetoCanvas(m,mw,mh,addP)
       end for
       end for
```

Algorithm 3.13: generate a wallpaper pattern of vertical *pg* group

Its motif contains only vertical glide reflection, so the pattern is generated in two directions by according to a given added point $addP(add.x, add.y)$, a given number of repeat x_repeat in vertical direction, number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_vGlideReflecion(\&m, \&m_w, \&m_h)$ to copy and flip a segment in vertical direction, after that translate an output for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas

3. Define a function $pg\_v(x\_repeat, y\_repeat)$ to generate a pattern

```
pg_v(x_repeat,y_repeat)
      Copy_vGlideReflection(m,mw,mh)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = sl.x + sw*j
            addP.y = sl.y + i*mh
      pastetoCanvas(m,mw,mh,addP)
end for
end for
```

Algorithm 3.14: generate a wallpaper pattern of horizontal *pg* group

Its motif contains only horizontal glide reflection, so the pattern is generated in two directions by according to a given added point $addP(add.x, add.y)$, a given number of repeat x_repeat in vertical direction, number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_hGlideReflecion(\&m, \&m_w, \&m_h)$ to copy and flip a segment in horizontal direction, after that translate an output for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $pg\_h(x\_repeat, y\_repeat)$ to generate a pattern

```
pg_H(x_repeat,y_repeat)
      Copy_hGlideReflection(m,mw,mh)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw) + j*mw
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

Algorithm 3.15: generate a wallpaper pattern of *p1* group

This group is similar to the *Hop* group of frieze pattern, but instead of repeating a motif in one direction this group repetitive displays the motif in two directions by following a given number of repeat x_repeat in horizontal direction and number of repeat y_repeat in vertical direction, and a given added point $addP$. Finally, the pattern is created based on x_repeat, y_repeat and $addP$. Steps of the algorithm as follows:

1. Define a function $paste(s, addP)$ to copy and paste the segment to the canvas
2. Define a function $p1(x\_repeat, y\_repeat\ )$ to generate a wallpaper pattern.

```
P1(x_repeat, x_repeat)
      For i=0 to x_repeat
      For j=0 to y_repeat
                  AddP.x = sP.x + sw*j
                  AddP.y = sP.y + i*sh
            paste(s,addP)
```

```
        End for
        End for
```

Algorithm 3.16: generate a wallpaper pattern of *pmm* group

Its motif contains the same geometric structure like symmetry of the d2 group. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction *and* number of repeat y_repeat in horizontal direction. Finally, the pattern is created based on x_repeat, y_repeat and $addP(add.x, add.y)$. Steps of the algorithm are:

1. Define a function $Copy\_vReflect\_hReflect(\&m, \&m_w, \&m_h)$ to copy and flip a segment in vertical direction, after that flip an output again in horizontal direction. Finally, a motif m *with size* m_w, m_h was computed
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $p2(x\_repeat, y\_repeat)$ to generate a pattern

```
P2(x_repeat,y_repeat)
      Copy_Rotate180_Translate(m,mw,mh)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x -sw)+2*sw*j
            addP.y = sl.y + i*mh
      pastetoCanvas(m,mw,mh,addP)
end for
end for
```

Algorithm 3.17: generate a wallpaper pattern of *cmm* group

To get a fundamental parallelogram (one repeat pattern) of the *cmm* group, the algorithm performs two steps. First it copies and applies vertical and horizontal reflections to a segment to form first half of the motif. In the second step, it applies a vertical reflection to the first half segment before translate the output by a given distance. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_vReflect\_hReflect\_Translate(\&m, \&m_w, \&m_h, d)$ to copy and apply vertical and horizontal reflection to a segment, after that apply vertical reflection and to an output before translate it for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $cmm(x\_repeat, y\_repeat)$ to generate a pattern

```
cmm(x_repeat,y_repeat)
      Copy_vReflect_hReflect_Translate(m,mw,mh,d)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
```

```
        addP.x = (sl.x-sw) + j*mw
        addP.y = sl.y + i*mh
        pastetoCanvas(m,mw,mh,addP)
    end for
    end for
```

Algorithm 3.18: generate a wallpaper pattern of vertical *pmg* group

To form a motif the algorithm performs two steps, first it copies and horizontal reflects a segment after that translate the segment. In the second step it applies vertical reflection to an output of the previous step. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_hGlideReflecion\_vReflect(\&m, \&m_w, \&m_h, d)$ to copy and horizontal reflect a segment, after that translate an output to form a first half segment of a motif. Finally, apply vertical reflection to that half segment for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $pmg\_v(x\_repeat, y\_repeat)$ to generate a pattern

```
pmg_v(x_repeat,y_repeat)
    Copy_hGlideReflection_vReflect(m,mw,mh,d)
    for  i=0  to x_repeat
    for  j=0  to y_repeat
        addP.x = (sl.x-sw) + j*mw
        addP.y = sl.y + i*mh
        pastetoCanvas(m,mw,mh,addP)
    end for
    end for
```

Algorithm 3.19: generate a wallpaper pattern of horizontal *pmg* group

To form a motif the algorithm performs two steps, first it copies and vertical reflects a segment after that translate the segment. In the second step it applies horizontal reflection to an output of the previous step. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_vGlideReflecion\_hReflect(\&m, \&m_w, \&m_h, d)$ to copy and vertical reflect a segment, after that translate an output to form a first half segment of a motif. Finally, apply horizontal reflection to that half segment for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $pmg\_h(x\_repeat, y\_repeat)$ to generate a pattern

```
pmg_h(x_repeat,y_repeat)
```

```
Copy_vGlideReflection_hReflect(m,mw,mh,d)
for  i=0  to x_repeat
for  j=0  to y_repeat
      addP.x = (sl.x-sw-1) + j*mw
      addP.y = sl.y + i*mh
      pastetoCanvas(m,mw,mh,addP)
end for
end for
```

Algorithm 3.20: generate a wallpaper pattern of *pgg* group

To get a fundamental parallelogram (one repeat pattern) of the vertical *cm* group, the algorithm performs two steps. First it copies and rotates a segment in 180 degree. In the second step, it applies a vertical reflection to an output of the previous step before translate it with a given distance. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_Rotate180\_vGlideReflect(\&m, \&m_w, \&m_h, d)$ to copy and rotate a segment in 180 degree, after that apply vertical reflection to an output before translate it for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $pgg(x\_repeat, y\_repeat)$ to generate a pattern

```
pgg(x_repeat,y_repeat)
      Copy_Rotate180_vGlideReflection(m,mw,mh,d)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw) + j*mw
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

Algorithm 3.21: generate a wallpaper pattern of *p2* group

Its motif is created like a motif of the *Spinning Hop* group, but the pattern is generated in two directions by according to a given added point $addP$, a given number of repeat x_repeat in vertical direction, number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_Rotate180\_Translate(\&m, \&m_w, \&m_h)$ to copy and rotate a segment in 180 degree, after that translate in d distance to generate a motif m *with size* m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif that generated from step1 to the canvas
3. Define a function $p2(x\_repeat, y\_repeat)$ to generate a pattern

```
P2(x_repeat,y_repeat)
      Copy_Rotate180_Translate(m,mw,mh)
```

```
        for  i=0  to x_repeat
        for  j=0  to y_repeat
              addP.x = (sl.x -sw)+2*sw*j
              addP.y = sl.y + i*sh
        pastetoCanvas(m,mw,mh,addP)
  end for
  end for
```

Algorithm 3.22: generate a wallpaper pattern of *p4* group

Its motif contains a symmetric structure like a motif of the *c4* group. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical *and* number of repeat y_repeat in horizontal directions. Finally, the pattern is created based on x_repeat, y_repeat and $addP(add.x, add.y)$. Steps of the algorithm are:

1. Define a function $Copy\_ThreeRotate90(\&m, \&m_w, \&m_h)$ to copy a segment s and apply three times 90 degree rotation to each rotation result, and then a motif m and its size m_w, m_h will be generated
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $p4(x\_repeat, y\_repeat)$ to generate a pattern

```
P4(x_repeat,y_repeat)
      Copy_ThreeRotate90(m,mw,mh)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw-1) + j*sw
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

Algorithm 3.23: generate a wallpaper pattern of *p4m* group

Its motif contains diagonal, vertical and horizontal reflections. The pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical *and* number of repeat y_repeat in horizontal directions. Steps of the algorithm are:

1. Define a function $Copy\_dReflect\_vReflect\_hReflect(\&m, \&m_w, \&m_h)$ to copy a segment s and apply diagonal, vertical and horizontal reflections respectively, after that a motif m and its size m_w, m_h will be generated
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $p4m(x\_repeat, y\_repeat)$ to generate a pattern

```
p4m(x_repeat,y_repeat)
      Copy_dReflect_vReflect_hReflect(m,mw,mh)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw-1) + j*sw
```

```
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

Algorithm 3.24: generate a wallpaper pattern of *p4g* group

To form a motif the algorithm performs two steps; first it copies and applies diagonal reflection to a segment s to form a quarter of the motif. In the second step, it applies rotation to the quarter segment to form the complete motif. Finally, the pattern is generated in two directions by according to a given added point $(add.x, add.y)$, a given number of repeat x_repeat in vertical direction and number of repeat y_repeat in horizontal direction and a given translation distance d. Steps of the algorithm are:

1. Define a function $Copy\_dReflect\_ThreeRotate90(\&m, \&m_w, \&m_h)$ to copy and applies diagonal reflection to a segment s to get 1/4 segment of a motif and then apply three time rotations of the quarter segment for getting a motif m and its size m_w, m_h
2. Define a function $PastetoCanvas(m, addP)$ to copy and paste a motif from step1 to the canvas
3. Define a function $p4g(x\_repeat, y\_repeat)$ to generate a pattern

```
p4g(x_repeat,y_repeat)
      Copy_dReflect_ThreeRotate90(m,mw,mh)
      for  i=0  to x_repeat
      for  j=0  to y_repeat
            addP.x = (sl.x-sw-1) + j*sw
            addP.y = sl.y + i*mh
            pastetoCanvas(m,mw,mh,addP)
      end for
      end for
```

3.3.2.2 Generating Patterns by a Simulation of Hand Floor-Loom's Components

Before introduce scientific term of design and weaving on floor-loom, we will explain general weaving concept on traditional floor-loom and weaving concept on Lao floor-loom. The introduction between both looms will show a concept why we need to simulate components of floor-loom. The traditional hand floor-loom used two main components called shaft (harness) and treadle to process weaving task, such as foot-treadle floor-loom or treadle loom and Dobby loom. There are at least two shafts and two treadles set up on the treadle loom in order to form weave structure in each weaving step. The shaft is used to hold a set of warps by inserting warp threads pass through heddles on the shaft; this process is called threading which defines which warp is tied to which shaft. The treadle is used to connect to the shafts where one treadle can be connected to more than one shaft. The tying between shafts and treadles is a guideline to generate a motif of pattern on woven fabric and it is called tie-up, when a treadle is pressed, then the tied shafts are depressed to open a shed for inserting weft by floating a shuttle from one side to another side. The sequence of pressing treadle is the sequence of weaving and it is called treadling. Treadle loom is widely used among hand weavers due to a loom with four shafts and four treadles can generate many appearances from simple to complex patterns. Since the treadle loom works by the combination between shafts and treadles, it restricts number of shafts and number of treadles on the loom. The maximum number of shafts on current commercial treadle loom is 32 while the maximum number of treadles is 16. The more number of shafts and treadles is the more variety of patterns we can make, but it is also need more time for making threading, tie-up and treadling. Making a pattern on the treadle loom shafts and treadles are always related, normally number of shaft and number of treadle are balanced or they are not too much different that is why the treadle loom is suitable only for making patterns with small motifs and geometrical motifs.

In contrast, traditional Lao floor-loom is commonly used three main components in weaving, first two components are set of two shafts and set of two treadles for weaving plain-weave or a ground-weave of fabric, and the third component is a supplementary shaft (supplementary heddles) that is a tool for weaving pattern on top of the fabric. According to term of weave technique, the traditional Lao floor-loom is indeed a hand dobby loom, its tools for making a pattern and making a ground-weave are obviously separated, the shafts and treadles are tools to weave the plain-weave where every single warp thread is passed through every single heddle on the shaft and each shaft is connected to each treadle. The supplementary shaft is a tool to store a draft of pattern where every two continuous warp threads are passed through its single heddle, each line of pattern draft is separated by a wooden line, each wooden line is grouped a set of heddles which determines how many warp threads are going to be lifted for making a pattern. The sequence of wooden line on the supplementary shaft is a sequence of generating a pattern. In order to tie each line of pattern during weaving, the plain-weave is woven after finish weaving each line of pattern-weave. The maximum number of wooden line stored on the loom depends on the length of the supplementary shaft, but normally if a pattern draft has more than 100 lines Lao weavers often use string instead of wooden line. This is an advantage of using supplementary shaft; it provides wide spaces for creating a pattern with big motif and with complex structure.

When we compare weaving method on the treadle loom to the method for making pattern draft on the supplementary shaft on Lao floor-loom, we found that they have similar idea. We can interpret number of shaft on treadle loom to number of wooden line on the supplementary shaft on Lao floor-loom, the Tie-up is a unique segment of symmetrical motif or it is an asymmetrical motif of a pattern. Thus, the combination of Tie-up and threading on treadle loom means determining set of heddles on the supplementary shaft on Lao floor-loom. Finally, treadling on treadle loom means the sequence of moving wooden line on Lao floor-loom for weaving a pattern.

Our investigated method for generating patterns in this section we are based on the advantage of the similarity between treadle loom and Lao floor-loom; we apply weave component on treadle loom to construct a draft of pattern for Lao floor-loom where the loom consists of four components namely: threading, tie-up, treadling and pattern. This method give benefit to both weaving on treadle loom and weaving on Lao floor-loom, it facilitates to design a pattern and to modify a pattern as well. Therefore, we use binary matrices to define threading, tie-up, treadling and pattern where the pattern matrix is a result of pattern generation from multiplication of other three binary matrices. The mathematical notations and mathematics equation of our method are illustrated as below:

$$P_{pXf} = T_{nXf} * I_{nXm}^{T} * H_{mXp} \tag{3.28}$$

P_{pXf} denotes a Pattern matrix, with p warp thread and f floating supplementary weft

T_{nXf} denotes a Treadling matrix, n indicates number of treadle and f indicates number of floating supplementary weft

I_{mXn} denotes a tie-up matrix, m indicates number of shaft and n indicates number of treadle

I_{nXm}^{T} denotes a transpose matrix of tie-up matrix

H_{mXp} denotes a Threading matrix, m indicates number of shaft and p indicates number of warp thread

Due to our binary matrices represent components of weave structure, so each row and each column of each matrix must contain at least one true value. On threading matrix, number of column means number of warp on the loom, so in each column must contain only one true value that means only one warp tied to one shaft. On treadling matrix, in each row contains only one true value, this means that there is only one treadle pressed or only one wooden line picked in each weaving step. For the tie-up matrix, its true values in each column interpret the tying point of shafts to each treadle. An example of pattern generation by this method illustrated in figure 3.16, a. is graphical feature of the Tie-up matrix, b. is a graphical feature of Treadling matrix while c. and d. are graphical features of Threading and Pattern matrices respectively. The black square on tie-up, Threading and Treadling matrices indicate true value while a white a square indicates false value while the color on the pattern matrix depends on warp’s color and weft’s color.

The investigated mathematics and algorithms for generating pattern only facilitate pattern design task, so we need more mathematics and algorithms for digitizing pattern-draft and weave-draft that they are understandable from both hand-weavers and weaving machines. We separately digitize pattern-drafts and weave-drafts because normally pattern-drafts are usable for both hand-weavers and electronic loom, but the pattern-drafts mainly give benefit to hand-weavers especially to Lao weavers for making manual pattern-drafts on the traditional floor-loom and digital patterns archiving. For digital weave-drafts are created for weaving machines, our investigated algorithms are to create digital weave-drafts for electronic looms that are able to weave fabric like traditional Lao textiles. Therefore, in the next section we are going to present standard file formats for digital pattern-drafts and algorithms for making digital weave-drafts.

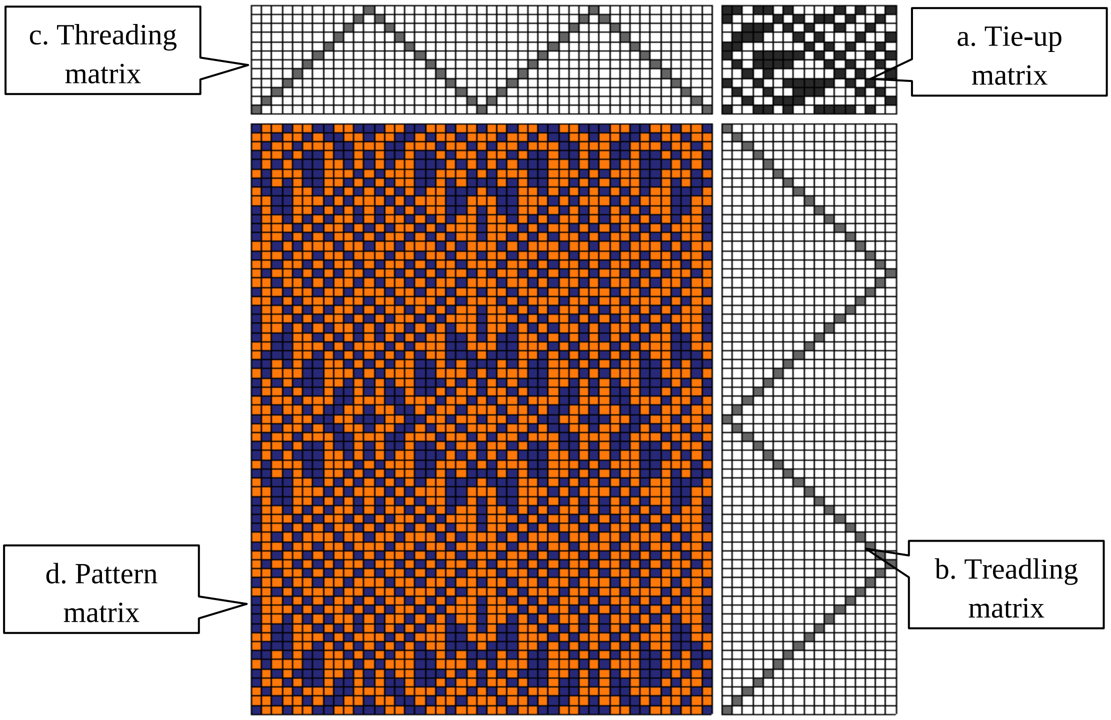


Figure 3.16
A graphical representation of weave components

3.3.3 Digitizing Pattern-drafts and Weave-drafts

As explained earlier, traditional Lao textile is applied compound-weave which is a combination of pattern-weave and ground-weave. The pattern-weave defines only structure of pattern while the ground-weave for Lao textile defines structure of plain-weave that means structure of pattern can be digitized separately from ground-weave. As a result, we define pattern-drafts to be digital drafts for pattern-weave while weave-drafts are defined to be digital drafts for compound-weave. The digital file format for digitizing in this research, we are based on two common standard file formats, the WIF file with .wif extension and image file with .bmp, .jpeg and .tiff extensions and so on. In this section we are going to explain how WIF file stores weaving data, and then follow by algorithm for getting WIF file from binary image file which is actually an inverse problem of WIF file, after that many algorithms for generating pattern-draft and weave-draft are presented respectively.

The WIF file is developed based on weave structure of Dobby hand floor-loom and it is created by implementing equation 3.28 and we follow WIF specification defined in [WIF specification] as well. Due to a pattern is generated by multiplication of three binary matrices, Tie-up, Threading and Treadling matrices, so instead of directly storing binary data of a pattern, WIF stores information of these three binary matrices. According to WIF specification, WIF file consists of a set of sections and key names, the section names are in brackets such as, [Weaving] section, [WARP] section and [WEFT] section. The key names are followed by an equal sign and the data, such as: shafts=16 and treadles=16. The sections are defined as "INFORMATIONAL" and "DATA" sections. For example, [WIF] section and [CONTENTS] section are informational section, where the [CONTENTS] section is a special informational section that lists all other included sections. Dimension and binary data of Tie-up, Threading and Treadling matrices are stored in specific data sections, such as number of shafts and number of treadles can be found in [WEAVING] section, number of warp threads is stored in [WARP] section, and number of weft threads is stored in [WEFT] section. Binary data for Tie-up matrix is listed in [TIEUP] section, number on the left equal sign indicate column's index while a sequence number on the right equal sign is a list of row's indexes on that column; [THREADING] section is listed binary data for Threading matrix, number on the left equal sign indicate column's index while a number on the right equal sign is row's index; and [TREADLING] section is listed binary data of Treadling matrix, number on the left equal sign indicate row's index while a number on the right equal sign is column's index. Instead of storing all binary data of matrices, WIF file is stored only row's index or column's index that has true value where the row's index or column's index on the right equal sign indicates row or column of matrix that has true value. By reading data in these sections from a given WIF file and work together with equation 3.28, we are able to generate a pattern matrix. Sequence numbers is shown in figure

```
[TIEUP]                      [THREADING]      [TREADLING]
17=11,10,8,6,4,3,1           1=1              1=1
16=12,10,9,7,5,4,2,1         2=2              2=2
15=12,11,9,8,6,5,3,2         3=3              3=3
14=11,10,8,7,6,4,2,1         4=4              4=4
13=12,10,9,7,5,3,2           5=5              5=5
12=11,9,8,6,4,3,2            6=6              6=6
11=12,10,9,7,5,3,2           7=7              7=7
10=11,10,8,6,5,2             8=8              8=8
9=12,11,9,7,6,5,2,1          9=9              9=9
8=12,10,8,6,5,1              10=10            10=10
7=11,9,8,5,3                 11=11            11=11
6=12,10,9,8,5,4,3,1          12=12            12=12
5=11,9,8,4,2,1               13=11            13=13
4=11,8,5,3,2                 14=10            14=14
3=12,11,8,7,6,4,3,1          15=9             15=15
2=11,10,7,5,4,2,1            16=8             16=16
1=10,9,6,5,3,2               17=7             17=17
```

Figure 3.17
Example data sections on WIF file of figure 3.16

3.17 are example [TIEUP], [THREADING] and [TREADLING] sections of WIF file format for a pattern is shown in figure 3.17.

A methodology for getting WIF file from a given pattern matrix is another aim of our digitizing. Nature of weaving makes some restrictions on Tie-up, Threading and Treadling matrices which is clue to compute binary data of those threes matrices. As we have known binary image is another format to represent digital motif and pattern if we compare a binary image to graphical feature of the pattern matrix in figure 3.16 we can see that a binary image is actually a pattern matrix where its extension can be .bmp, .jpeg or .tiff. WIF file stores binary data of the three matrices for generating a pattern in equation 3.28 while a binary image contains directly binary data of a pattern by observation we found a linkage between a WIF file and a binary image, the basic idea of their relationship was introduced by Ralph E. Griswold in 2004 [64] he showed that pattern matrix was an inverse problem of WIF file. Technically, we can say that binary image file format and WIF file are inverse problem of each other, this means from a given binary image we can get WIF file and from a given WIF file we can get a binary image file. The detail of algorithm to find WIF file from a pattern matrix is explained as follows:

The algorithm can be separated into two steps, firstly is to find unique row of the pattern matrix from this step we will get Treadling's sequence and row's number of Tie-up matrix. The second step is to find unique column of the pattern matrix from this step we will get completed Tie-up matrix and Threading's sequence, and then finally we got a WIF file. To perform algorithm we define notations, P is a pattern matrix, R is a row matrix, C is column matrix and T is a Tieup matrix.

Algorithms 3.25: Inverse problem of WIF file format

The steps of the algorithm are:

Step1: Find a unique row of pattern matrix and store in the R matrix. A treadling sequence is used to store row's index of R when checking duplicated row.

```
If    first row of P          then
      Add first of P to be first row of R
      Add row's index of R to treadling sequence
End if
Else  check P's row and R's row
      If    P's row is duplicated on R's row    then
            Add current row's index of R to treadling sequence
      End if
            Else
                  Add current row of P to be a new row of R
                  Add  current  row's  index  of  R  to  treadling
                  sequence
            End else
      End else
```

Step2: Find a unique column of pattern matrix and store in the T matrix, in this step we transpose R and store to C, after that find unique row of C and store in T. Threading sequence is used to store row's index of T when checking duplicated row.

```
If    first row of C          then
```

```
        Add the row to be first row of T
        Add row's index of T to threading sequence
End if
Else  check C's row and T's row
        If    C's row is duplicated on T's row    then
              Add current row's index of T to threading sequence
        End if
        Else
              Add current row of C to be a new row of T
              Add current row's index of T to threading sequence
        End else
End else
```

A graphical representation of the algorithm 3.25 shows in figure 3.18.

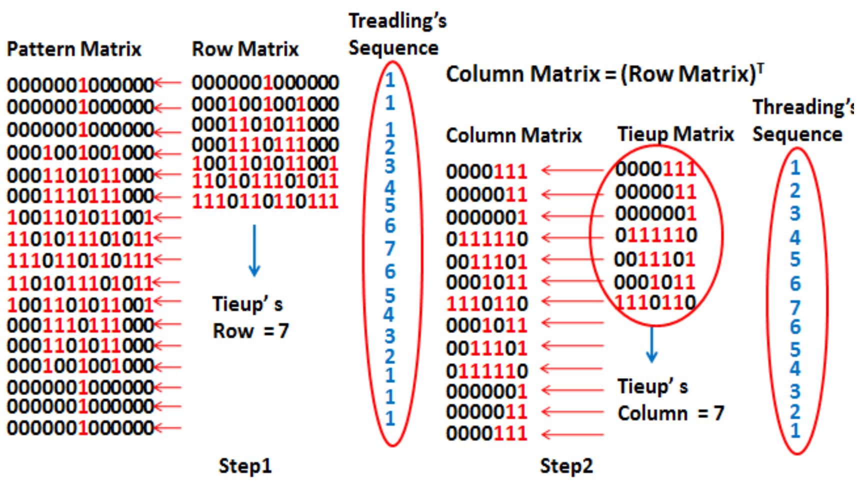


Figure 3.18
A graphical representation of Inverse problem of WIF file

Due to weaving machines works with digital drafts, so the digital pattern-drafts in both image file format and WIF file format are input files for weaving on electronic looms. However, as mentioned in chapter 2 there are many types of commercial looms and almost looms has their own software to set up and to create final digital weave-draft for weaving on the looms. Therefore, in our research we observed some electronic looms where the digital pattern-drafts for traditional Lao floor-loom are compatible to them. The study on electronic looms helps us to understand how the electronic looms work, and the study also help us to fill the gap between traditional Lao weaving technique and the modern weaving techniques. We restrict the observation on three electronic looms namely: Dobby loom, digital Jacquard loom and TC2 (Thread Controller Number 2) loom, because these three electronic looms are widely used among textile industry and they are developed based on traditional hand floor-loom. Actually, electronic looms are able to weave many kinds of fabrics, so the complex on the weave structures depends on their given digital weave-drafts. In industrial textiles, many weave structures are developed and they are creatively applied where the combination of weave structures on the fabrics is up to creativity of designers and it depends on the capacity of the looms. However, generally the electronic looms read only binary data on the given drafts and the drafts are read row by row in order to make interlacement between warps and wefts. Therefore, to weave textiles like traditional Lao style on the electronic looms is not a big deal if we know their weaving techniques and use the suitable looms, the important thing need to provide to the looms is the right digital weave-drafts. The right digital weave-drafts mean the drafts that machines can read and can produce traditional Lao textiles on them. Weaving on the electronic loom is basically the same as weaving on the hand floor-loom, such as lifting identified warps for inserting wefts and weaving keep working forward step by step, the difference is only that every weaving step on the hand floor-loom is done by hand while on the electronic loom every weaving step is done by machine. As a result, we investigated algorithms to generate digital weave-drafts for the observed electronic looms, the algorithms are developed based on characteristics of Lao textiles and two considering points of Lao weaving technique. Firstly traditional Lao weaving technique is always used two weave structures, a ground-weave and a pattern-weave that means we need a weave-draft to tell a machine to weave this combination structure, and secondly the most Lao textiles are colorful fabrics which are used more than one weft for pattern-weave, so weavers have to define how many wefts are intended to use during weaving. According to these requirements, our developed algorithms basically concern about pattern-weave and ground-weave, such as algorithm for generating weave-draft by separating weft's index, algorithm for adding ground weave to pattern-weave and algorithm for removing ground weave from pattern-weave. We are going to explain the developed algorithms that are related to digitize weave-drafts as following section and we will start from an algorithm for separating weft index on a pattern-weave.

3.3.3.1 Separating Weft Set by Indexing

Technically weaving on automatic electronic loom is impossible to automatic float many wefts (or many shuttles) through one shed, if we intend to weave a fabric with multiple wefts is necessary to tell the machine to open a shed for each weft separately. In commercial weave design software is often used color to identify weft set and used together with many image processing techniques provided in the software, so the process to get a weave-draft is complicate and weavers need much time to understand the software. Therefore in our research we use indexing technique to assign index to each set of weft which means the same weft set can assign many colors, this technique is good for designers since design task to weave-draft generating, because they are freely able to design colorful pattern, the visualized colorful pattern will be used as guideline to weave colorful pattern on the loom while the weave-draft that generated according to assigned weft's index is a guideline to lift warps for weaving. As a result, our developed algorithm is used to separate different weft set into different line on the digital draft, the idea is that from a given digital pattern-draft, we assign weft's index on the pattern as input of the algorithm after that the algorithm will automatic separate the set of wefts regard to their defined index. The main reason of separating the set of wefts is because every single weaving step the machine lifts warp threads for inserting weft to form woven structure, so the separated wefts in each line on the draft is a guideline to tell the machine to open a shed by lifting identified group of warps on the line.

The output of digital weave-drafts from a given colorful pattern-draft is flexible; the final draft is up to type of machine and the imagination of weavers. If we need a digital weave-draft for automatic weaving machine, so number of color is a number of wefts used in weaving, each color means each different weft. However, if we need a digital weave-draft for semi-automatic weaving machine, number of color is independent from number of weft. For instance, if we work on TC2 loom or any thread controller loom which is semi-automatic loom, the machine only response to lift set of warps for opening a shed then a weaver has to float a shuttle (a weft) by herself/himself. In this case, weft indexes on a weave-draft are used for defining group of lifted warps in each weaving step, but during weaving weavers can use many wefts in one step, because floating weft is done by weavers. This drafting is good for weaving with embroidery technique or weft-face patterning technique which is a main used technique in hand-weaving for traditional Lao textile. Weave-drafts for semi-automatic loom are directly interpreted weaving on hand floor-loom, each line on the draft explain weaving step on the hand floor-loom. So, from graphical feature of weave-draft or image file format, weavers are easy to understand and follow the drafts. To perform algorithm we define necessary notations as follows:

M_{mXn}	is a single weave with multiple weft indexes
W	is a weave-draft with separate weft indexes
w	is row's number of weave-draft
$r[m]$	is an 1D integer array of size m, it uses to store highest weft-index of each row

Algorithm 3.26: separate by weft index

Steps of algorithm are:

1. Find highest weft-index in each row, a pseudo code is:
```
for i=0 to i=m-1
       r[i] = 0
      for j=0 to j=n-1
            if(r[i]<M[i][j].weftIndex)
                  r[i] = M[i][j].weftIndex
            end if

            else
                  r[i]= 1;
            end else
      end for
end for
```

2. Compute row's number of weave-draft, a pseudo code is:
```
w=0
for i=0 to i=m-1
```

```
      w=w+r[i]
end for
```

3. Define dimension of weave-draft: W_{wXn}
4. Separate different weft-index in different row by checking weft-index of a single-weave matrix with highest index of each row $r[m]$, if weft-index less than highest index then separate the index into different, a pseudo code is:

```
int c=0,i=0;
while(i<w)
for j=0 to j=n-1
      for   k=0 to k=r[i]-1
            //check weft-index of single-weave
            if(M[c][j].weftIndex == k+1)
                  S[i+k][j] = M[c][j]
            end if
            else
                        S[i+k][j] = 0
                  end else
            end for
      end for
      i=i+r[i]
      c++
      end while
```

3.3.3.2 Adding Ground-weave to Pattern-drafts by Considering Weft's Index

The digital weave-draft for weaving traditional Lao textiles on electronic loom is a draft of compound-weave between pattern-weave and ground-weave, so to create a weave-draft we need to add ground-weave to a given pattern-draft. Therefore, we investigated algorithms for adding ground-weave, because a pattern-draft is an input for creating weave-draft, we divide the algorithms into two cases, the algorithm in the first case is to add ground-weave after considering the index of wefts. The weave-drafts generated in this case are aimed to support weaving colorful pattern while the developed algorithm in the second case is to add ground-weave without considering weft's index. The application of algorithm depends on purpose of weaving, if weavers intends to use only one weft's set then the algorithm in case 2 is suitable, but if weavers intend to use multiple weft's set for weaving colorful pattern then the algorithm in first case is suitable. The idea on adding ground-weave is normally to loopy inserting each line of ground-weave to each line of pattern-draft. In this section we are going to present only the algorithm of the first case, the algorithm contains two steps, the step for separating weft's index and the step for adding ground-weave to the result of the first step. To perform algorithm we define necessary notations as follows:

S_{mXn}	is a single weave with multiple weft indexes
G_{pXn}	is a ground-weave
C	is a compound-weave
w	is summation all highest weft-index from each row

$r[m]$	is 1D array of size m of 2D point (x,y), where r[m].x uses to store weft-index of row, r[m].y use to store highest weft-index of row.
$rId[m]$	is 1D array of string of size m

Algorithm 3.27: adding ground-weave to pattern-draft by considering weft's index

Steps of the algorithm are:

1. Find highest weft-index in each row, a pseudo code is:

```
for i=0 to i=m-1
        r[i].x = 0, r[i].y=0
      for j=0 to j=n-1
            if(r[i].x <S[i][j].weftIndex)
                  r[i].x = S[i][j].weftIndex
                  r[i].y++
            end if
            else
                  r[i].x = r[i].x;
            end else
      end for
      rId[i]=r[i].x
end for
```

2. Compute summation of highest-index from all rows, a pseudo code is:

```
w=0
for i=0 to i=m-1
      w=w+r[i].y
end for
```

3. Define dimension of compound-weave: $C_{(w+m-1,n)}$
4. Generate compound-weave by assigning values of single-weave and ground-weave to the matrix of compound-weave with three different cases. The pseudo code is:

```
int addPoint, c=0,i=0
while(i<w)
addPoint++
if(i==0)//case1
      for j=0 to j=n-1
            int intrId=0
            for   k=0 to k=r[c].y-1
                  intrId = int(rId[c][k])
                  //check weft-index of single-weave
                  if(M[c][j].weftIndex == intrId)
                        C[i+k][j] = M[c][j]
                  end if
                  else
                        S[i+k][j] = 0
                  end else
                  C[i+k][j] = G[addPoint%p][j]
            end for
```

```
        end for
    end if


    else //case2
        if(r[c].y>1)
                int intrId=0
                for j=0 to j=n-1
                        for   k=0 to k=r[c].y-1
                                intrId = int(rId[c][k])
                                //check weft-index
                                if(M[c][j].weftIndex == intrId)
                                        C[i+c+k][j] = M[c][j]
                                end if
                                else
                                        S[i+c+k][j] = 0
                                end else
                        end for
                        if(c<m-1)
                            C[i+c+r[i].y][j] = G[addPoint%k][j]
                        end if
                end for

            else //case3
                int intrId=0
                for j=0 to j=n-1
                        for   k=0 to k=r[c].y-1
                                intrId = int(rId[c][k])
                                //check weft-index
                                if(M[c][j].weftIndex == intrId)
                                        C[i+c+k][j] = M[c][j]
                                end if
                                else
                                        S[i+c+k][j] = 0
                                end else
                        end for
                        if(c<m-1)
                            C[i+c+r[i].y][j] = G[addPoint%k][j]
                        end if
                end for
            end else
        end else
        I = i+r[c].y
        c++
    end while
```

3.3.3.3 Adding Ground-Weave to Pattern-drafts without Considering Weft's Index

The algorithm for adding ground-weave to pattern-draft without considering index of wefts is aimed to generate weave-draft for weaving with only one weft's set on pattern-weave. The algorithm works similar to the first case except that it contains only one main task to loopy add each line of ground-weave to each line of pattern-draft. Generally, in this case color and weft's index in a pattern-draft do not play any role to the algorithm, their role is only to visualize the pattern to the weavers. Therefore, number of line on the weave-draft is a result of multiplication between row's number of ground-weave and row's number of pattern-draft minus one. Suppose a given pattern-draft $P_{m\,X\,n}$ and a ground-weave $G_{p\,X\,n}$ we can get a weave-draft $W_{(m*p)-1\,X\,n}$.

Algorithm 3.28: adding ground-weave to pattern-draft by considering weft's index

1. Define dimension of a ground-weave : G_{kXn}
2. Define dimension of a compound-weave : $C_{(2m-1)Xn}$
3. Add ground-weave to pattern-weave, a pseudo code is:

```
int countOdd = 0
int countEven = 0
for int i=0 to i=2*m-2
//assign plainweave to compoundweave
   if((i%2)!=0)
      countOdd++
      for int j=0 to j=n-1
        C[i][j] = G[countOdd%k][j]
        //No.row of plainweave = k
      end for
    end if
   // assign singleweave to compoundweave
   else
      for int j=0 to j=n-1
          C[i][j] = G[countEven][j];
      End for
      countEven++;
   end else
end for
```

3.3.3.4 Removing Ground-weave from Weave-drafts

Since digital drafting in our research works on two kinds of drafting, pattern-draft and weave-draft, the algorithms for adding and removing ground-weave are necessary methods for changing drafts from pattern-draft to weave-draft and vice-versa. As we have seen in previous sections the algorithm 3.27 and the algorithm 3.28 are used for generating weave-draft from pattern-draft. The idea of removing ground-weave is to move each line of ground-weave out from the weave-draft. The result depends on which algorithm was applied, if the weave-draft is generated from algorithm 3. 27 the output is a pattern-draft with separated weft's index, but if the weave-draft is generated from algorithm 3. 28 the output is a pattern-draft without separated weft's index.

Chapter 4

Practical Implementation

In this chapter we will discuss implementation tasks by dividing the implementation into two parts. In the first part we developed design modules where they are intended to satisfy the characteristics of traditional Lao textiles. Because the design task for making Lao textiles is complicated from motif construction to textile designs, we separately created three design modules to support specific design task. The first module is called LT-Tieup, it plays important role for digitizing motifs and patterns, including digital design to digital drafting. This module implemented a variety of algorithms introduced in chapter 3. The second module named LT-Weave; it is mainly used for pattern modification and for visualizing the weave structure of patterns. Due to traditional style of Lao textiles always decorate with many patterns, to support this characteristic we developed a module named LT-Design to provide textile design and textile visualization. The module facilitates users to edit a specific pattern by opening a window of the LT-Weave; users are also able to edit the Tieup element of the pattern by linking to a window of the LT-Tieup module. The LT-Design aims to support the flexibility in textile design as well as flexibility in modification of textile's elements.

The second part of the implementation we created online repository for online digital archiving and cultural preservation. The contents of the website contains four main sections, the first section introduces general information of Lao textiles, and then the second section specify the information and development tools for generating each textile elements. In this content briefly explain the three design tools that we are going to discuss their detail in this chapter. The third section is about collections and exhibitions of our digital data models, a collection subsection is a place to store and to provide all available digital motifs/patterns to users, the collection is subdivided into a collection of digital motifs, a collection of digital patterns and a collection of digital textiles. For the exhibition subsection shows interesting data models, it is organized similar to the collection subsection by subdividing many exhibitions. The last section is a section for contribution; this section facilitates users to contribute their designs or their digital drafts in order to share them among weavers. The other sections in the website are additional information of the textiles and a brief introduction of our research project.

We will start detail of this chapter by presenting implementation of the LT-Tieup module in section 4.1, the implementation of the LT-weave module will be introduced in section 4.2, after that section 4.3 will discuss the implementation of the LT-Design module. The workflow of the three developed modules will be explained afterward. The development of the online repository will be the last section of this chapter and it will be illustrated in section 4.5.

4.1 LT-TieUp Module

The LT-TieUp module was developed as a tool to support Digitizing motifs and patterns in two separated tasks, namely digital design and digital drafting. A main component of the LT-Tieup module was a canvas which provided as a design area, the canvas component was formed as pointed paper, any digitizing task works on the canvas, such as: design a new motif, generate a new pattern or import a predefined motif. Actually, the canvas component is a graphical feature of a binary matrix where its cells (squares) have only two possible statuses true or false, such as: if we clicked on active cell then the active cell would turn to be non-active cell and vice versa. The module uses foreground color to determine active cells or true values; background color uses to determine non-active cells or false values. Any design on the canvas means we assign data to the binary matrix after complete design designers are able to save or export the design into three available formats, text file, WIF file or image file formats.

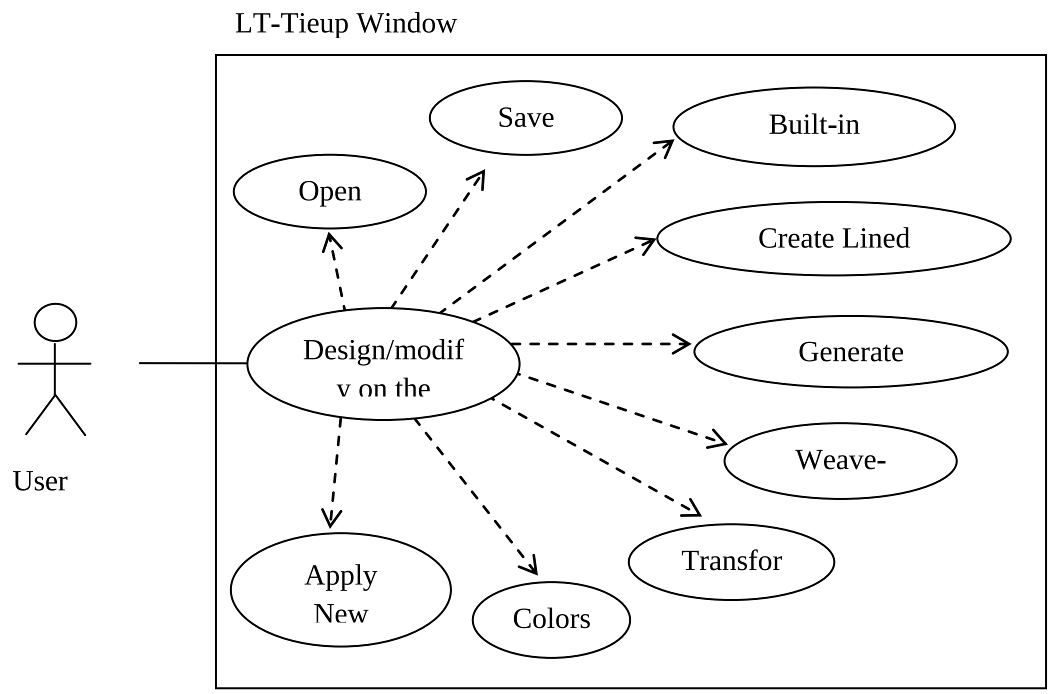


Figure 4.1
A *Use Case* diagram of the LT-Tieup module

To explain the module in technical terms, we will refer to a *Use Case* diagram that is shown in figure 4.1. The *Use Case* diagram present only first level of the LT-Tieup module, because we want to keep the diagram to be simple as much as possible, during explain each *Use Case* we will explain its sublevel simultaneously. This diagram indicates that the canvas is a main component for users to work with; every *Use Case* provided on the module works together with the canvas. The users can directly create any design with the canvas or users are able to import digital files to the canvas by using *Open File* case, there are three available file formats provided namely .bmp, .wif and .txt formats. Similar to the *Save File* case, it also provides three available file formats for exporting a complete design; especially for the image file format, the users are able to save the design as binary image or as colorful image. On the case of *Built-in Motifs* provides predefined single motifs, this case contains five subcases by following number of motif categories mentioned before. On the case of *Creating Lined Motif*, the module provides predefined segment of lined motifs and steps for generating them. To generate any pattern, users have to work with the case of *Generating Pattern*; this case contains two subcases, a case for *Generating Frieze Pattern* by defining number of repeat in one-direction, and a case for *Generating Wallpaper Pattern* by defining number of repeat in vertical and horizontal directions. On the *Weave-draft* case, the users are able to generate pattern-drafts by freely defining number of weft-index on the pattern or to generate weave-drafts from pattern-drafts or remove ground-weave from pattern-drafts. The *Colors* case is used to define color of design due to weft-index and color-index are different; this helps users to be able to define many colors for one weft-index. To update the new set up, when applied new color or new weft-index or when edited them, users have to use the case of *Apply New Setup*. The last *Use Case* is a case of transform segments of motifs; this case is to facilitate motif constructing task, particularly for constructing symmetry motifs.

To develop the LT-Tieup module we used object oriented programming approach. As mentioned earlier the canvas is only a component to work with when using the LT-Tieup module. Therefore, number of required classes is small, two main classes play important role in this module; the first class was named *BMatrix* that contained general attributes of a binary matrix. The second class was named *Canvas* which inherited from the *BMatrix* class. However, when we compared number of defined classes to the number of mathematical formulas and algorithms that implemented in the module, they are very different. The *Canvas* class contained many attributes especially function attributes. For motifs construction, the mathematical concepts of cyclic and dihedral groups were implemented by constructing their geometric structures in the module. Additionally, the LT-Tiep module was provided symmetry operations to facilitate motif modification. To support flexibility of Lao motifs, predefined traditional motifs were embedded in the module. According to two different styles of traditional motifs we categorized the predefined motifs into a category of lined motifs and a category of single motifs. Based on numerous types of single motifs, the category was organized into five subcategories, a category of *Naga*, a category of *Siho*, a category of *Giant*, a category of *Bird* and finally a category of *Other* motifs. Figure 4.2 shows captured main window of the LT-Tieup module, figure 4.3 shows example of a lined motif on the canvas and figure 4.4 shows example of a single motif on the canvas respectively.

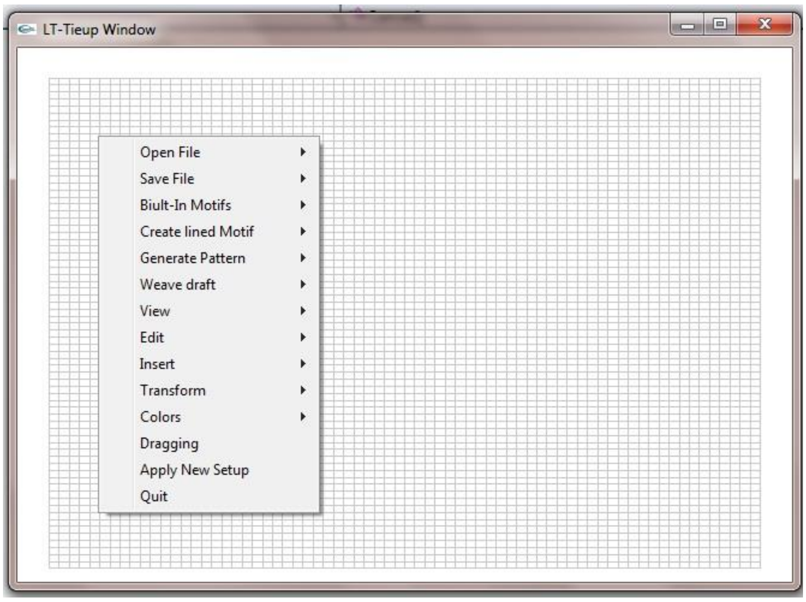


Figure 4.2
A window of the LT-Tieup module with a popup menu

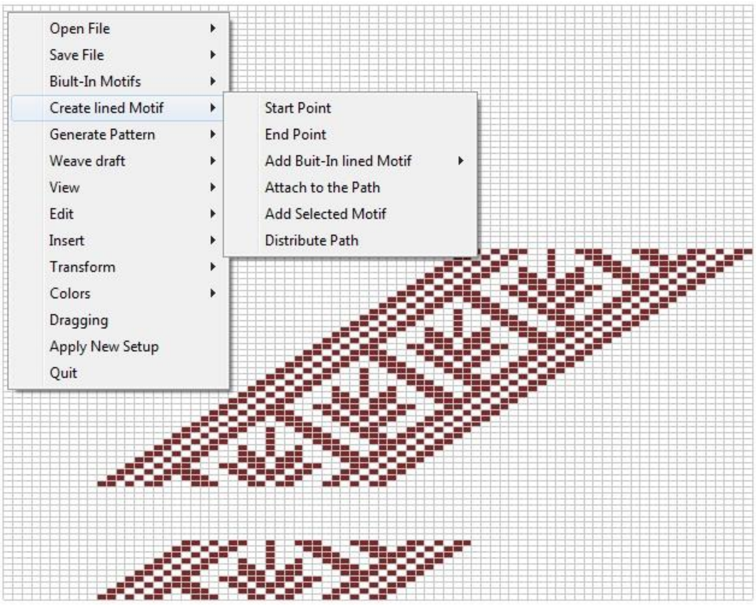


Figure 4.3
An example of a generated lined motif on the canvas

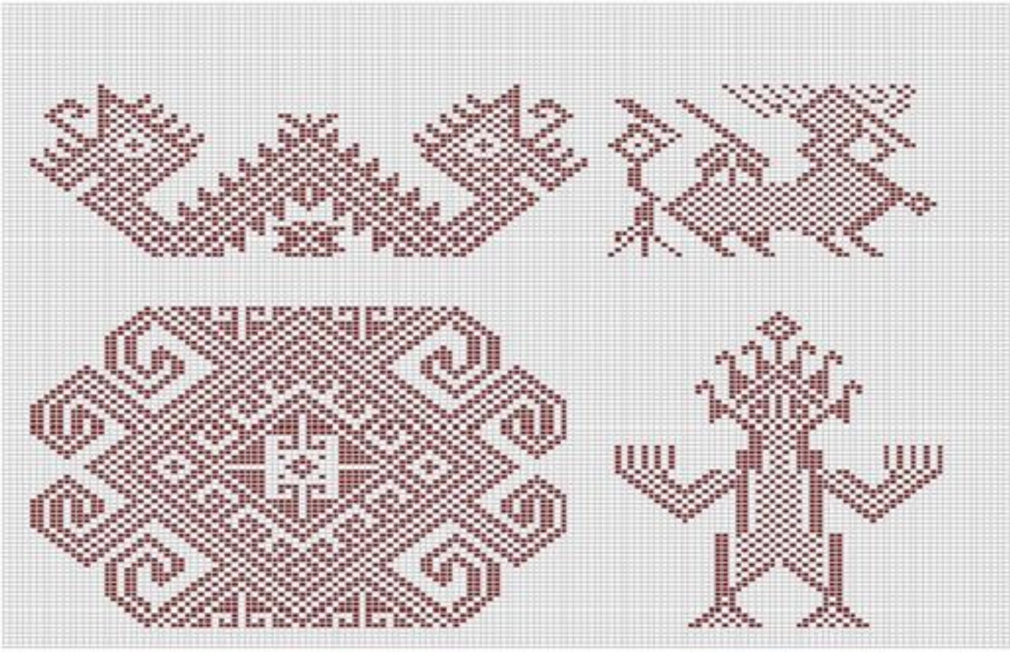


Figure 4.4
Examples of single motifs on the canvas

To generate patterns, the algorithms for generating Frieze patterns and wallpaper patterns were implemented. To create Frieze patterns, the module was constructed geometric structures of 7 Frieze groups. Similarly for creating wallpaper patterns, the module was constructed geometric structures of 12 wallpaper groups with totally 16 two-directional pattern styles. Number of repeat motif on the patterns defines by values for repetition, if only one repetitive value assigned means generating one-directional patterns, if two repetitive values assigned means generating two-directional patterns, by default the module set values to three. The implementation of the patterns generation was one of time consuming task, because a variety of symmetry groups had to be implemented, totally 23 algorithms. The geometric structures were various from group to group, but after implemented them inside the module they become simple functions to apply. Figure 4.5 shows an example of a Frieze pattern with three repetitive motifs generated by the LT-Tieup module.

For generating digital drafts, the algorithms for pattern-draft and weave-draft were implemented. The module provided list of weft-indexes to define pattern-drafts for weaving that need multiple weft-sets. The general concept of generating weave-draft is to add ground-weave to pattern-draft, thus the output of weave-draft depends on its given pattern-draft. Changing between pattern-draft and weave-draft is simple, because we implemented the algorithms for adding ground-weave and for removing ground-weave in the module. The experiment on how this module generates various cases of weave-drafts will be shown in chapter 5.

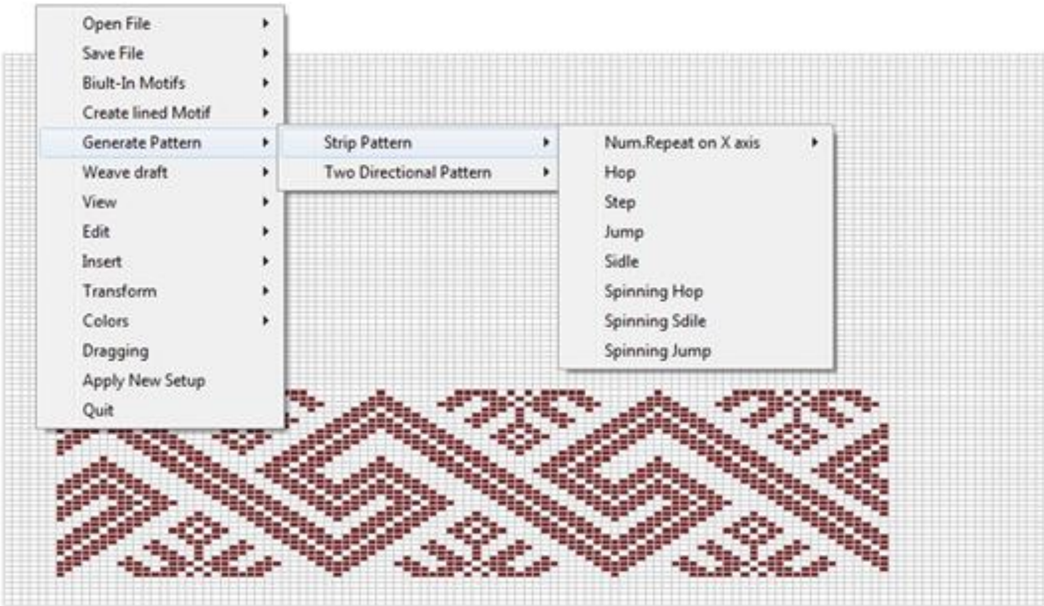


Figure 4.5
An example of generative Frieze pattern on the canvas with three repetitive motifs

4.2 LT-Weave Module

The LT-Weave module was developed as a tool for pattern design and pattern modification. The module was simulated weave components of traditional handed floor-loom which would be easy to understand for hand-weavers. The mathematical equation 3.28 (see section 3.3.2.2 in chapter 3, page 68) was implemented in this module to support particular work on each weave component. The module works directly with WIF file, the graphical window of the module consists of four components that look the same as graphical feature of the WIF file. Because the WIF file stores weaving information of all weave component of the floor-loom, what we design or edit on the window is what we will exactly get on the WIF file. The LT-Weave module was also implemented the algorithm 3.25 (see section 3.3.3 in chapter 3, page 71) for computing inverse problem of the WIF file. The benefit of implementing this algorithm is to provide flexibility for switching between WIF file and image file, as example illustrated in chapter 3 in figure 3.18. To support traditional style of Lao patterns and to introduce some traditional patterns to users, roughly 30 predefined traditional patterns were embedded inside the module. The original patterns of these predefined patterns were taken from traditional Lao textiles and some of them were generated from predefined motifs provided in the LT-Tieup module.

To explain how the LT-Weave module work and react to users we would like to explain the detail of module by using *Use Case* diagram showed in figure 4.6. The diagram shows only main *Use Cases*, while there are three cases that users always work with; the first case is for design and modifying the *Tieup* component, the second case is to work with *Threading* component and third main case is for design and modifying the *Treadling* component. A pattern is generated after users used these three cases. The module provides available three file formats .bmp, .wif and .txt formats for importing files and saving files. The case of *Open File* is for importing files and a case of *Save File* is for saving files. For loading predefined patterns to the weave components, the users have to use *Bilt-in Patterns* case. In case the user wants to assign or change color of weft threads and warp threads, the users have to use case of *Weft Colors* and *Warp Colors* respectively.

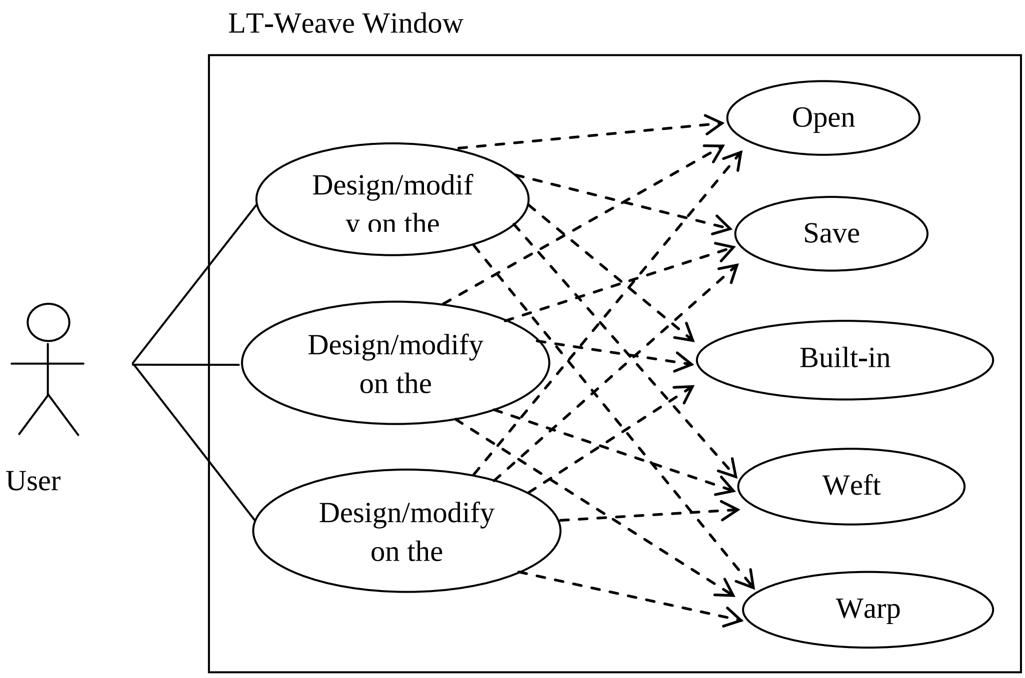


Figure 4.6
A *Use Case* diagram of the LT-Weave module

The LT-Weave module consists of four components namely *Tieup*, *Threading*, *Treadling* and *Pattern*. It is similar ideas to the *Canvas* component of the LT-Tieup module; these components were formed as pointed papers to support design and modification. Actually, they are graphical features of binary matrices defined in equation 3.18 (see page 68); they were implemented by following all the constraints assigned in the matrices. Therefore, in each column of the *Threading* component can has only one active cell or one true value, in each row of the *Treadling* component can has only one active cell. The *Pattern* component is used to visualize a result of the combination of others three components. Five main classes play important role to develop the LT-Weave module, a *BMatrix* class was used to contain general attributed of a binary matrix. This class was already defined in the LT-Tieup module, because we developed each module separately, so we need the *BMatrix* class in this module as well. The others four classes were classes of weave components; we named the classes the same name as the components' names. They were *Tieup*, *Threading*, *Treadling* and *Pattern* classes where these classes inherited definitely from the *BMatrix* class. Because *Threading* and *Treadling* are used to determine appearance of patterns, so functions for manipulating sequences on the components were required, such as: a function to create a diagonal sequence in vertical or horizontal reflections. For the *Tieup* component works generally like the canvas of the LT-Tieup module, but its design area is limited to a size of current motif while its modification result directly affect to the motif's appearance of the current pattern. As a result, some required functions attributes were assigned on the *Tieup* class to facilitate motif manipulation on the *Tieup* component. Normally, designers do nothing on the Pattern component, the component just used to show the appearance of pattern. However, in technical terms the *Pattern* class needed a lot of function attributes, the most algorithms for pattern design and pattern modification were implemented in this class. Figure 4.7 shows a window of the LT-Weave module with a popup menu.

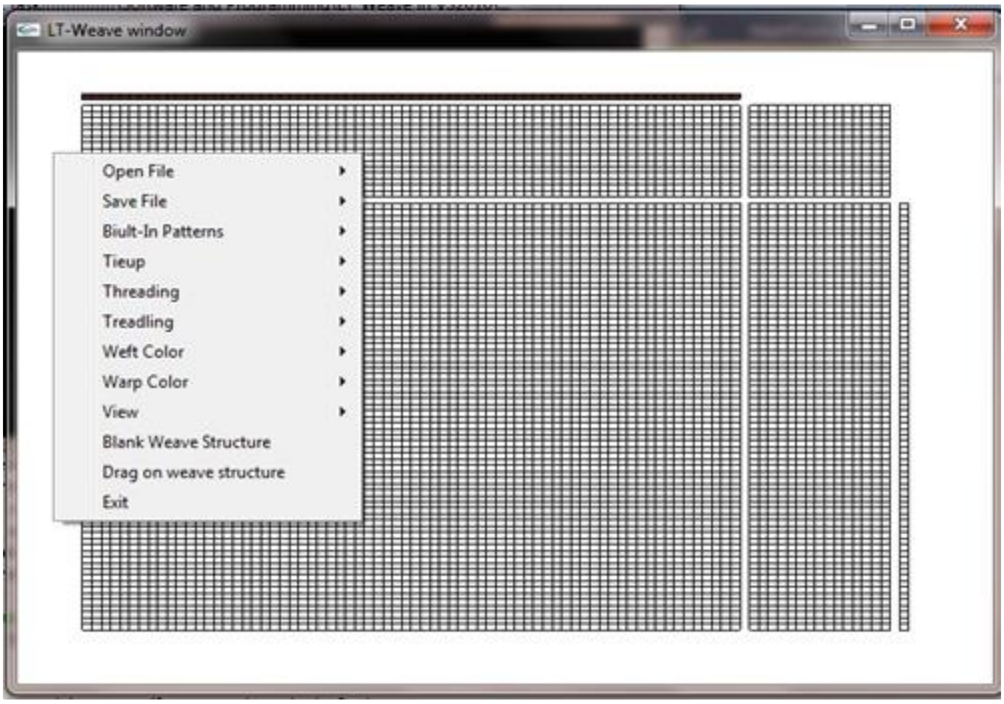


Figure 4.7
A window of the LT-Weave module with a popup menu

4.3 LT-Design Module

The LT-Design module was developed as a tool for textile design and textile modification. In order to support flexibility in design, the module was embedded the LT-Weave and LT-Tieup modules and provided three separated windows, the main window is for working with textile design; one sub-window is for pattern modification which is a window of the LT-Weave module and another sub-window is for motif modification which is a window of the LT-Tieup module. Based on the style of Lao textile that contains at least one pattern, so to design any textile on the module it requires at least one pattern to import to the module. Therefore, on the main window is provided a *Canvas* component, but the *Canvas* in this module works different from the *Canvas* on the LT-Tieup module. The *Canvas* is served as ground-weave (or plain weave) where all imported patterns are visualized as decorative patterns on the textile. It provides users to rearrange or to modify particular pattern, and it provides a link to the window of the LT-Weave module to modify the pattern. To enhance a motif modification of specific pattern, the module provides a link from the *Tieup* component of the LT-Weave module to the window of the LT-Tieup module. In conclusion, the window of the LT-Weave module is a sub-window of the LT-Design module while the window of the LT-Tieup module is a sub-window of the LT-Weave module.

Technical representation of the module represented by a *Use Case* diagram showed in figure 4.8. The diagram indicates that working with a canvas is a main *Use Case* of the module; on the canvas users are able to import multiple digital patterns by using *Open File* case. In contrast, for exporting any complete digital textile users have to use a case of *Save File*. As illustrated in the diagram there are two extended *Use Cases*, a case for opening a window of the LT-Weave module and a case for opening a window of the LT-Tieup module. The window of the LT-Weave module can be opened when a user is modifying the specific pattern. Similarly, the window of the LT-Tieup module can be opened when a user is modifying on the *Tieup* component of the LT-Weave window.

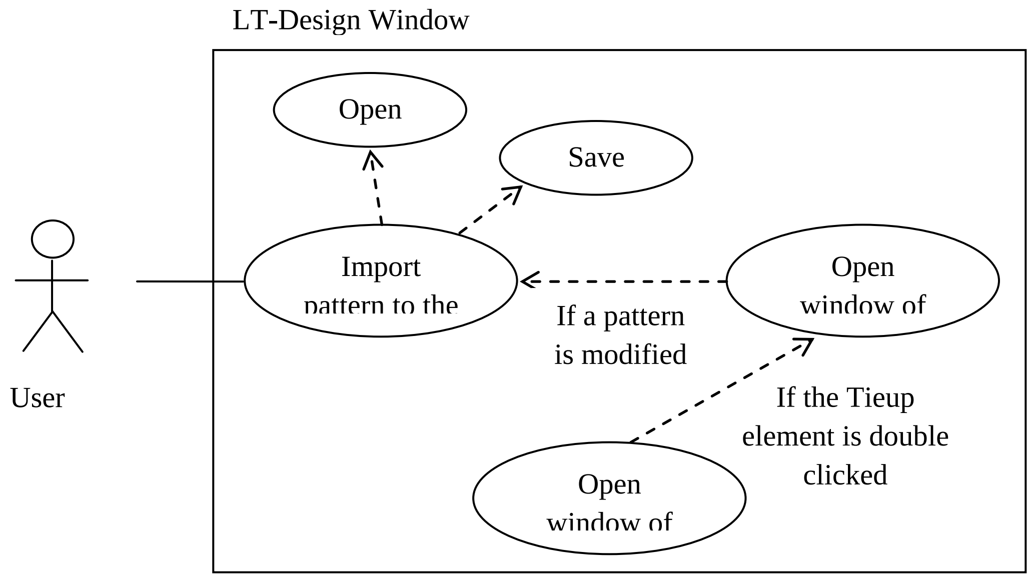


Figure 4.8
A *Use Case* diagram of the LT-Design module

Actually, if digital patterns formed in image formats we can use any computer graphics software to arrange them on the canvas in order to form as a textile and it will be easy to visualize the design output. However, if we would like to edit a particular part of a particular pattern this would be a different task for general computer graphics software, especially for a task to generate a weave-draft of a complete designed textile. Because the *Canvas* of the LT-Design module is graphical feature of a binary matrix, while its default values of the *Canvas* matrix are false. The imported patterns are formed as other binary matrices when digitizing textile the LT-Design will merge values of the *Pattern* matrices to be values of the *Canvas*'s elements. To develop the LT-Design module, we still used object oriented programming approach by implementing three in one module. We call three in one module because this module was implemented components of itself and it was implemented components of the LT-Weave and the LT-Tieup modules. Therefore, all the defined classes from two previous modules were reused in this module, and we defined one more extra class for implementing the *Canvas* of the LT-Design module, named *ltdCanvas* class. Finally, we got main classes for developing the LT-Design module.

Even though the modules LT-weave and LT-Tieup were already embedded inside the LT-Design module, but they were implemented as auxiliary tools to strengthen ability for modifying pattern element of current digital textile on the LT-Design module. As a result, the stand-alone LT-Weave and the stand-alone LT-Tieup modules still need to support individual design and modification tasks. To present overall concept of the three developed modules and their linkage, we are going to explain a workflow of them in the following section.

4.4 Workflow of Three Lao Textile (LT) Design Modules

The workflow of three developed modules expressed in figure 4.9. We will start to explain a linkage between the LT-Tieup and the LT-Weave modules by first look at the ability for import/export digital files, these two modules support three different formats namely, .bmp, .wif and .txt formats, this means that generally outputs of the LT-Tieup module are usable as inputs of the LT-Weave module and vice versa. As the name of the LT-Tieup implies, this module produces motifs of patterns where the motifs are able to import to the *Tieup* component of the LT-weave module, after that users have to define Threading and Treadling sequences in order to produce a pattern. By implementing a useful algorithm 3.25 (see section 3.3.3 in chapter 3, page 71), users are able to import generated motifs and patterns from the LT-Tieup module to modify in the LT-Weave module. Simultaneously, outputs of motifs and patterns from the LT-Weave module are able to import to modify in the LT-Tieup module as well.

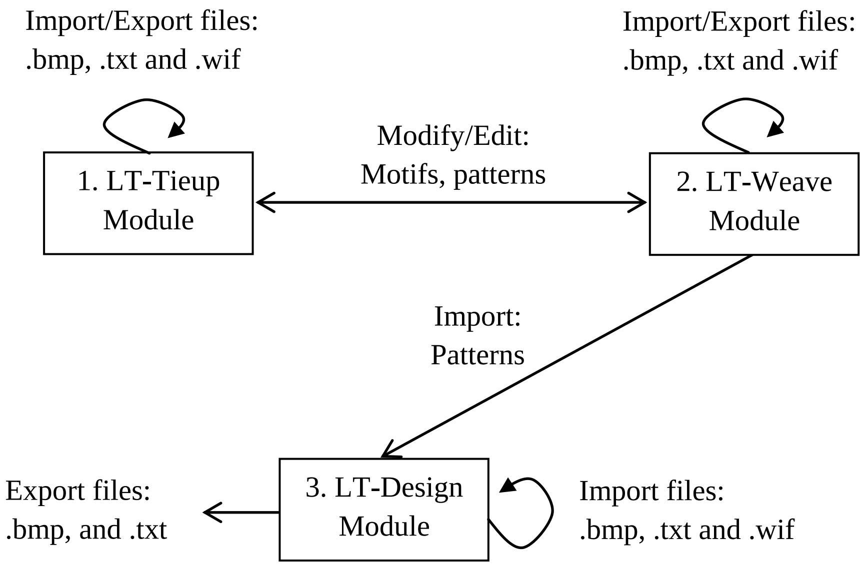


Figure 4.9
A workflow diagram of three Lao textile design modules

For importing digital patterns to the *Canvas*, the LT-Design module supports three different digital file formats like other modules, but the module provides only two available file formats, namely .bmp and .txt file formats for exporting digital textiles, due to size of textiles are big and their weave structures are complicated because they are a combination of many patterns, so the module was implemented only image file and text file formats for storing digital textiles. Because the LT-Weave was already embedded inside the LT-Design module, the stand-alone LT-Weave module is just a tool to support digital patterns to the LT-Design module, but for modification the LT-Design module uses its own auxiliary tools. The overall concept of this workflow is the LT-Tieup module supported digital motifs to the LT-Weave module for pattern design while the LT-Weave module supports digital patterns to the LT-Design module for textile design.

4.5 Online Repository

The online repository was developed as a tool for online digital archiving and cultural preservation. The aim of the development is not only to store digital file of traditional Lao textiles, but is also used as a tool for communication among weavers, researchers and cultural heritage experts. Before we introduce a tool to develop the website, we will start to explain overall technical concept of the online repository by following *Use Case* diagram illustrated in figure 4.10. The online repository or the website consists of three actors, visitor, user and administrator. There are three available *Use Cases* for general visitors, the *Search Items* case is for searching list of items or a specific item on the website. The visitors are able to search and display digital data on the *Collection* and *Exhibits* pages, but they are not able to leave comments on the page; they do not allow to download and to upload digital files in order to get allowance they have to register to be members of the website.

In contrast to registered users, they have more *Use Cases* than visitors. The *Login* case is used for allowing registered users to login to the website. After login to the website, a *Profile* page will be displayed for current user; the users are able to modify their profile at any time during login status. In addition, the case of *Leave Comment* provides users to be able to leave comments on subpages of the *Collection* and *Exhibition* pages. The case of *Download Items* provides users to be able to download any provided digital file while the case of *Contribute Items* allows users to upload their digital files.

The *Use Cases* for administrator are specific on two managing tasks, managing users and managing items. On the case of *Manage User*, administrator has responsibility to accept a registration of a visitor for being new members of the website or to reject a registration. In the subcase of *Delete User* provides administrator to be able to delete existing users from the website. One more subcase is for blocking users, the users are temporary inactivated, their accounts will be activated again when administrator unblock them. On the case of *Manage Items*, administrator has five subcases. The first three subcases are about managing comments, such as: approve comments, disapprove comments and remove comments. Other two subcases are a case of *Update Collection* and a case of *Update Exhibition*, these update cases include modifying, adding and deleting. An extended concept of the website was presented by a page flow diagram in figure 4.11; this diagram shows a whole structure of the website and shows the flow between pages.

Because the aim of the website is to support both cultural promotion and cultural preservation, information of traditional Lao textile is main input to the website. The type of required data to store in the repository is various, such as: photo, description, information of motif, patterns and textile, the most important data is digital data model of motifs, patterns and textiles. As a result, a web content management system is a suitable tool to store such data. Therefore, we contacted to staffs of the Cluster of Asia and Europe of Heidelberg University, Mr. Eric Decker and Mr. Mathias Arnold who are a coordinator and a member of the Heidelberg Research Architecture (Cluster of Excellence) respectively. Finally we decided to use an open source web content management system named Omeka to be a tool for developing our online repository. Omeka records data in a form of metadata by providing international standard metadata schema named *Dublin Core*. Its records of data called *Items*; *Item* is a metadata that consists of a set of attributes or element to describe resource. For more detail about Omeka see [67]. Structure of the website and a flow between web pages is illustrated in figure 4.11. Detail of data stored in each page will be explained in the following section.

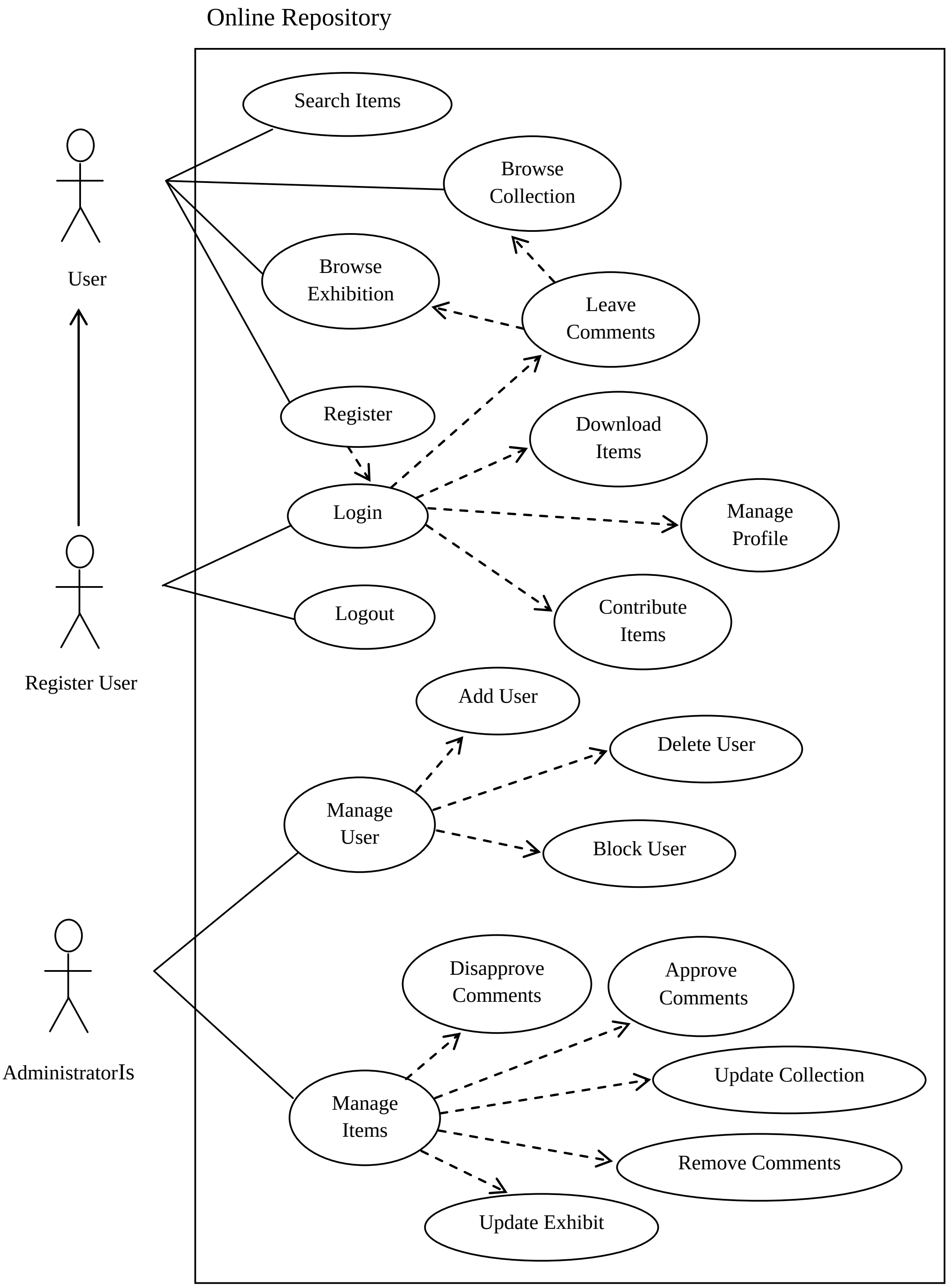


Figure 4.10
A *use case* diagram of the online repository

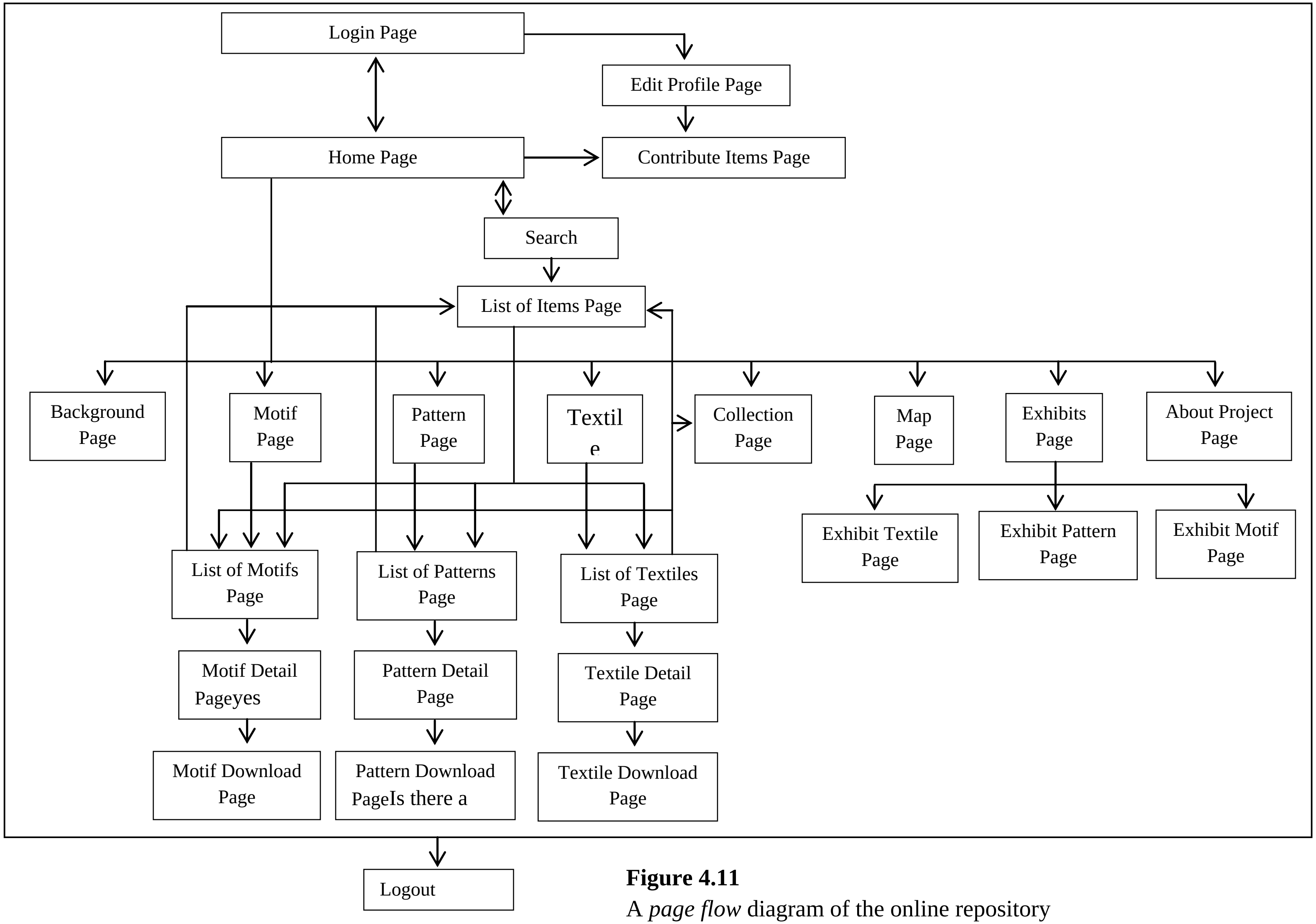


Figure 4.11
A *page flow* diagram of the online repository

After the traditional digital motifs, patterns and textiles were generated by the three design modules, all of them were used as digital data models to store in a database of a website. Contents on the website arranged from general to specific as showed in figure 4.12. A background and characteristics of traditional Lao textiles was a started page, some details of Lao textiles, motifs and patterns components in chapter 2 re-introduced again in this web page.

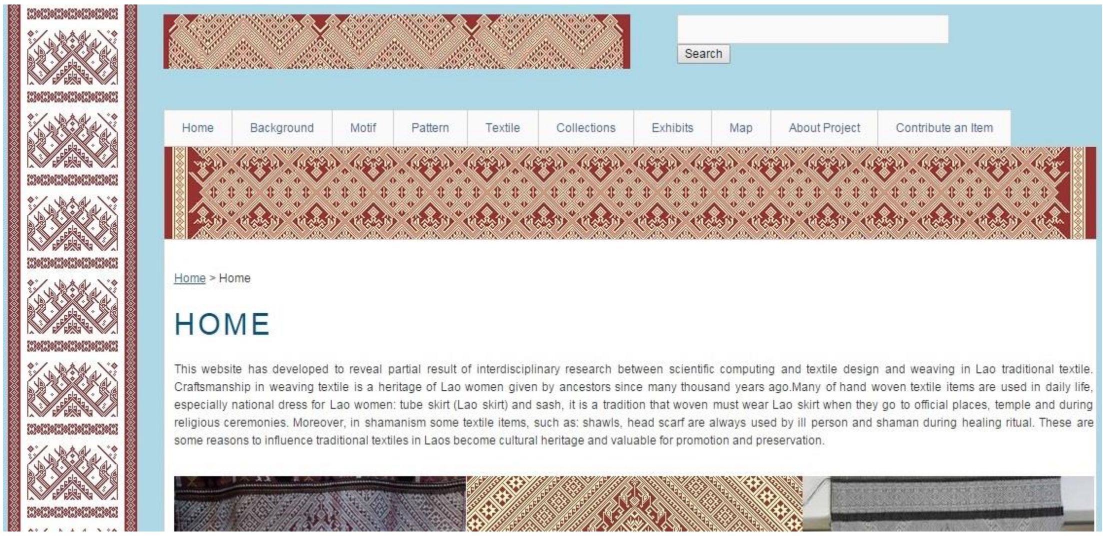


Figure 4.12
A captured *Home* page of the online repository

To specify types of data models, we separated each type in different page, *Motif*, *Pattern* and *Textile* pages. On the *Motif* page, the information of the LT-Tieup module is presented and described as a main tool for digitizing motifs, the page provides a link to go through a list of motif's data models, if visitors are users of the website, the page will provide a link to download them. The similar arrangement on the *Pattern* page, it provides information of the LT-Weave module which is a main tool for patterns generation and patterns modification. Moreover, the page also contains a link to a list of pattern's data models and a link for downloading them. On the *Textile* page, the LT-Design module is introduced; a link to textile's data models and a link for downloading are respectively provided. To support flexibility in searching and display the digital data, the website assembles all digital data models in the *Collection* page which contains links to each type of data model. The details of data flowing between pages are showed on *Page flow* diagram in figure 4.11.

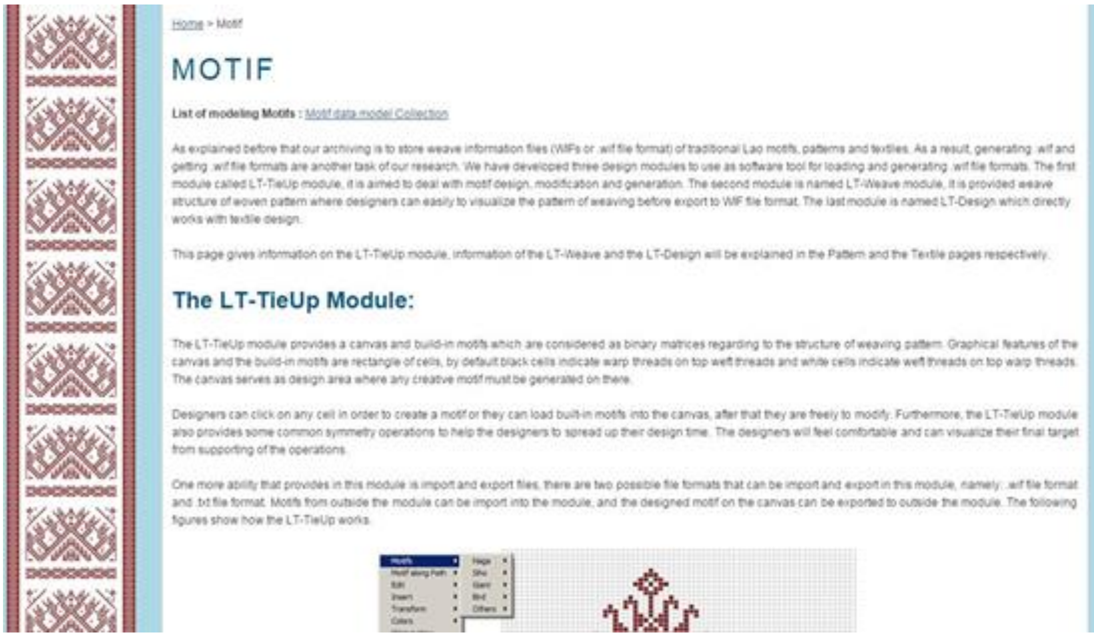


Figure 4.13
A captured *Motif* page of the online repository

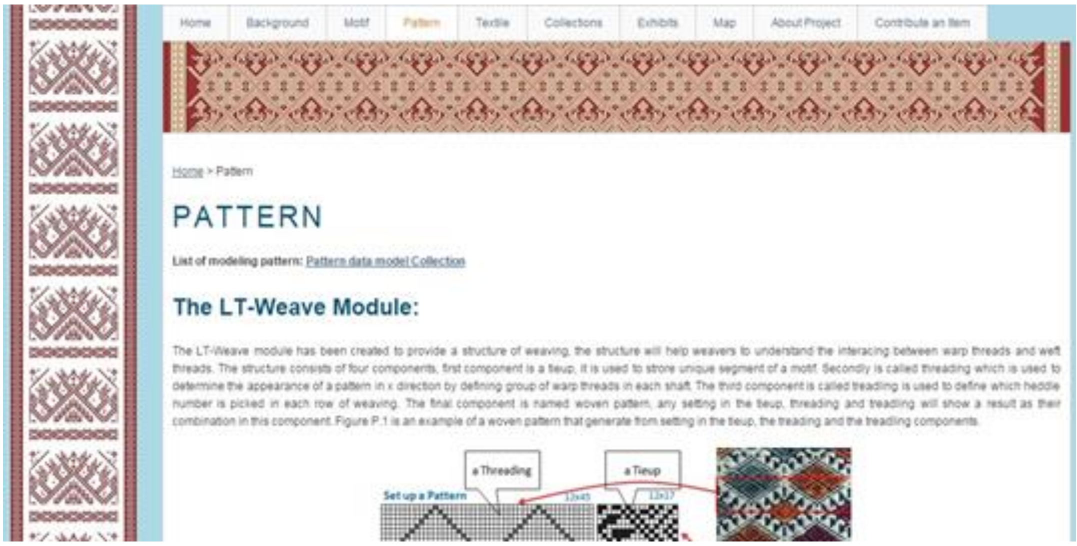


Figure 4.14
A captured *Pattern* page of the online repository

Figure 4.15
A captured *Textile* page of the online repository

Additional option for browsing on the website, we created a *Map* page to support search facility by regarding the location on the map.

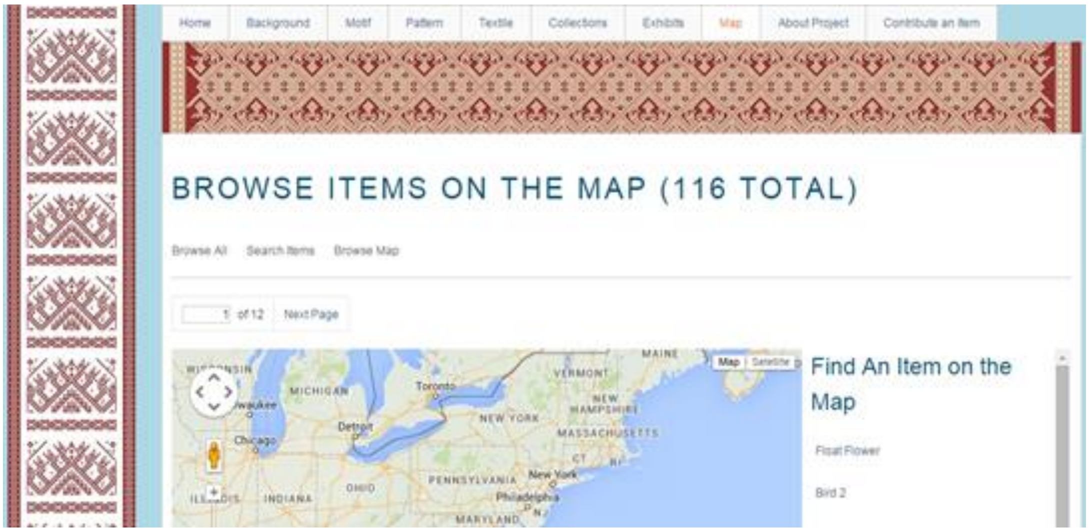


Figure 4.16
A captured *Map* page of the online repository

To show interesting motifs, patterns and textiles, we created *Exhibits* page to be a place for exhibition and promotion the beauty and value of traditional Lao culture. As introduced in the beginning of the section, the website supports not only for downloading digital data models to the users, but the website also support contribution facility by allowing users to upload their digital files to the website.

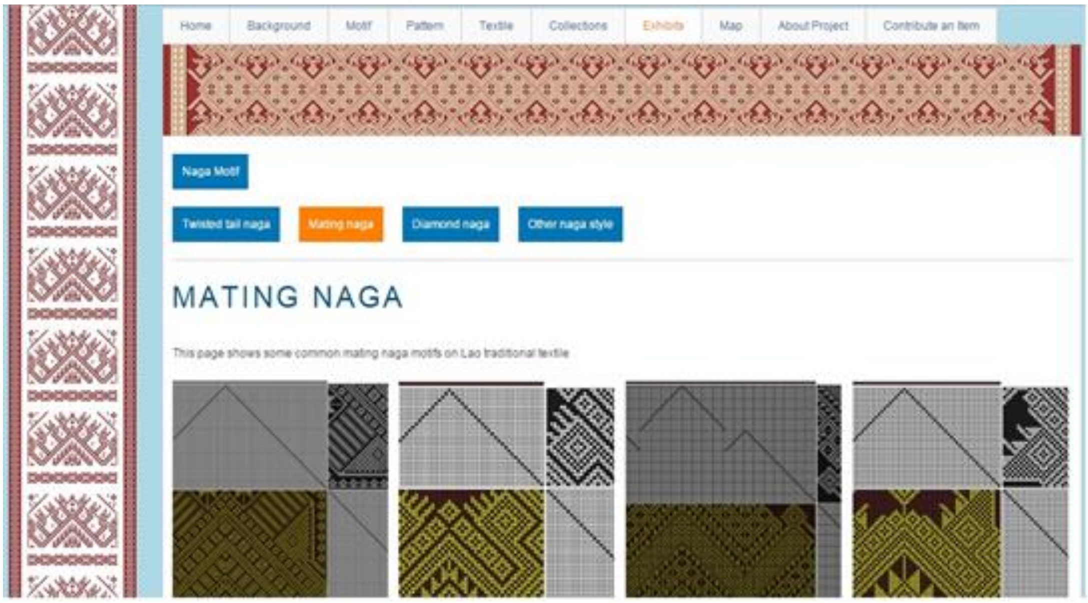


Figure 4.17
A captured *Exhibit* page of the online repository

Figure 4.18
A captured *Register* page of the online repository

Chapter 5

Experiment and Result

In chapter 3 we introduced techniques to digitize motifs, patterns and weave-drafts. Their implementation was shown in chapter 4. In this chapter we are going to experiment on those techniques by using our design modules as the experiment's tools. Before we go to details of each experiment, we will introduce a workflow of using the Lao Textile (LT) design modules. The experiment will start from digitizing motifs and patterns in each style, after that making a comparison of their results. Making digital pattern-drafts and weave-drafts will be explained in weaving section. To experiment on weaving, we will test our digital weave-drafts with the modern electronic TC2 loom (see page 19) which its working concept is similar to hand floor-loom used in Laos. A variety style of weave-drafts are generated and tested with the TC2 loom, the discussion on weaving results will be end part of this chapter.

5.1 Experiment and Result on Digitizing

The aim of digitizing is to produce digital data models for archiving and for electronic weave. The digital data models consist of digital motif, pattern, textile and weave-draft. To digitize such data models, the modules LT-Tieup, LT-Weave and LT-Design are tools. We use the LT-Tieup to generate digital motifs, patterns and weave-drafts; the LT-Weave is used to modify the digital data models; the LT-Design for digital textile decoration. The original motifs and patterns for the experiments are selected from traditional textiles which are popular designs among Lao designers. Therefore, we will explain workflow for using those modules then we will present details of the experiment.

5.1.1 Workflow for Using Lao Textile (LT) Design Modules

To explain the usage LT design modules in the experiment we present their workflow illustrates in figure 5.1. The three of four digital data are created by using the LT-Tieup module, such data are motifs, patterns and weave-drafts. For generating digital motifs, the LT-Tieup module is a useful tool because it provides lot of facilities to generate all types of motifs, such as lined and single motifs. Due to the geometric structures of Frieze group and wallpaper group were implemented in the module, thus generating digital patterns is a comfortable task for this module. To create digital structures of Frieze group and wallpaper group were implemented in the module, thus generating digital patterns is a comfortable task for this module. To create digital weave-drafts, the module provides a variety of weave functions to generate the drafts. We use the module to digitize pattern-drafts and weave-drafts that are aimed to use for weaving experiment.

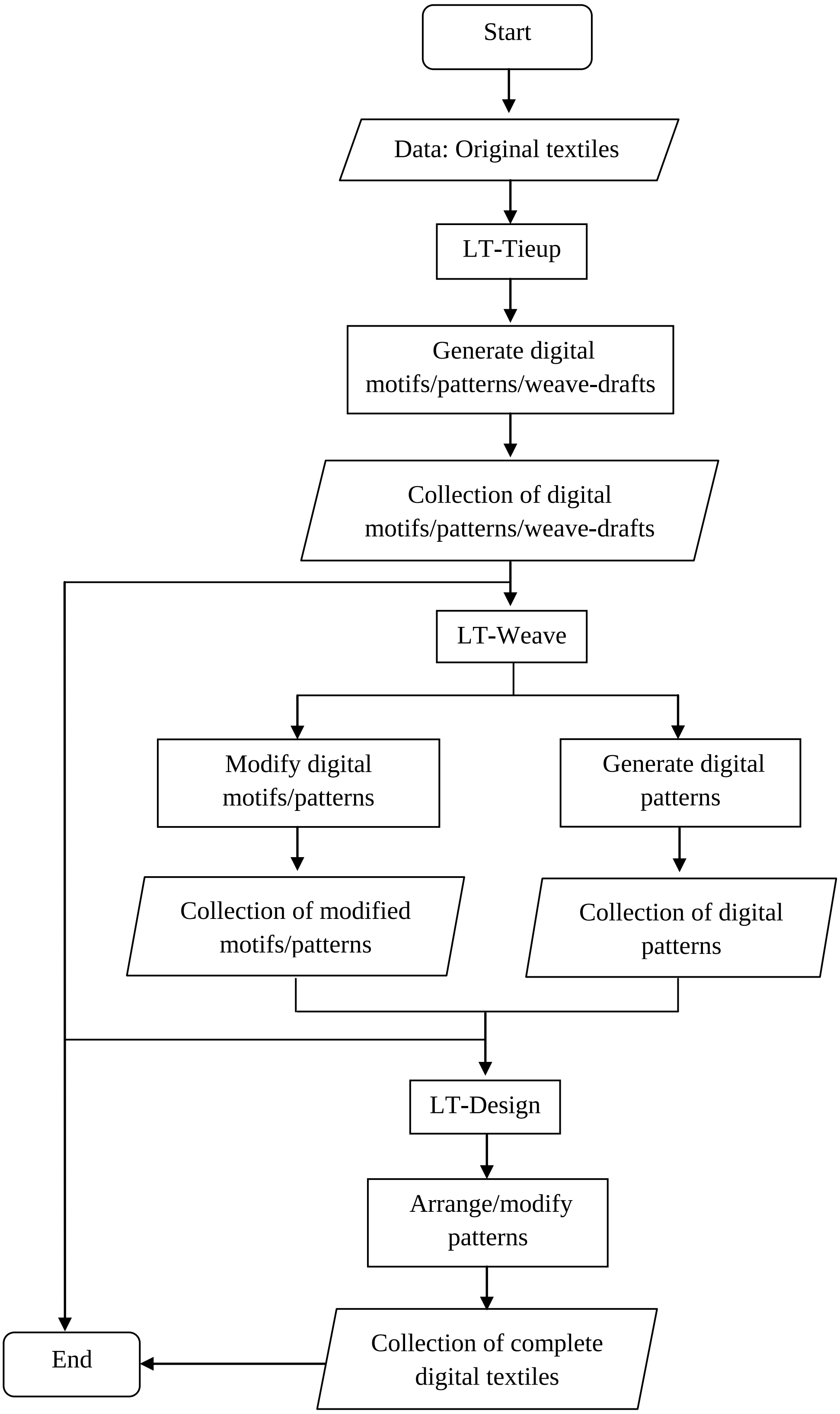


Figure 5.1
A workflow diagram for using Lao Textile (LT) design modules

In terms of design, a motif is an element of pattern or another word a motif is one repeat pattern. We often need some edit and modification before getting a complete design, particularly to modify existing motifs and patterns. Therefore, we mainly use the LT-Weave module to modify the digital motifs and patterns. Because the module simulated weave components of floor-loom, it makes modification become simple task. In addition, we also use the module to create some new patterns by importing existing motifs. Generally, the LT-Weave module provides both modification and generation of the digital data.

The LT-Design is additional module to design and to visualize digital textiles. Regarding characteristics of Lao textile, a pattern is an element of textile and one textile contains more than one pattern. To digitize the textiles, we only need to import patterns to the module. The patterns are arranged to form a textile, each pattern is modified by linking to a window of the LT-weave module. In conclusion, the aim for using each module depends on a target of output. If the target is digital motifs then we use the LT-Tieup module. If the target is digital patterns, we are able to use both the modules LT-Tieup or LT-Weave, but the LT-Weave module is recommended for pattern modification. If we need digital textiles, the LT-design only is a suitable tool. The experiment on digitizing focuses on generating digital motifs and digital patterns excluding digital pattern-drafts and weave-drafts. For digitizing pattern-drafts and weave-drafts, we include them in the experiment on weaving that will be a last section of this chapter. The experiment contains digitizing motifs and patterns, details of their generation will be explained as follows.

5.1.2 Generating Lined Motifs

Motif name: *Diamond of Naga head*
Item type: found on a shawl of Tai Daeng Ethnic
Source: Phaeng Mai gallery, Vientiane capital

In this section we are going to experiment on how to generate lined motifs and use them to generate a big hierarchical motif by using the LT-Tieup module. We use a motif of *Diamond of Naga head* in figure 5.2 as our target; the figure 5.2 is an original photo of the motif which was taken from Phaeng Mai gallery. The motif is symmetric, if we look in detail it was constructed by many lined motifs. So, if we would like to generate a motif that looks the same as showed on the photo, first we have to count how many lined motifs are needed for one quarter, after that create each lined motif and arrange them by following the original design, the final step is just to apply symmetry operations for generating a full symmetric motif.
According to the photo we defined eight lined motifs and a quarter segment of a *small diamond* which is innermost layer of the motif, totally we have nine components needed to be generated, illustrate from figure 5.3 to figure 5.6. The LT-Tieup module was implemented orientation of design in clockwise direction, so a required segment for generating a symmetric motif is always a first quarter of the motif. Therefore, a lined motif is always generated along a path with slope equal to one. To avoid any conflict between lined motifs, the component should always be generated from inner

to outer where arrangement is from right to left. A component defined in figure 5.3 is an innermost component and figure 5.6.a shows an outermost component of the motif.

Figure 5.2
A photo of big motif, *diamond of Naga head* and flowers.

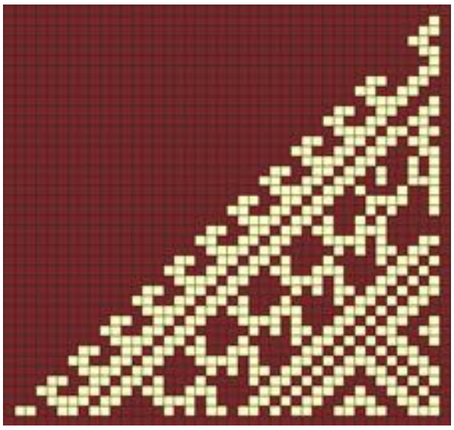
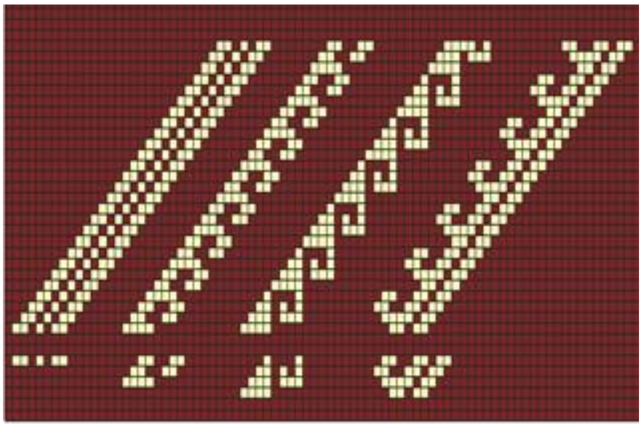


Figure 5.3
A new created *diamond* motif
(Size 33 x 38)

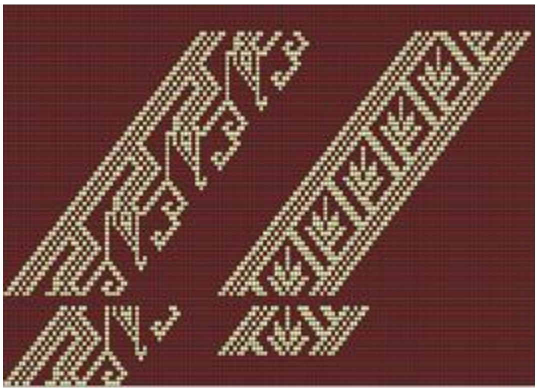


(a). (b). (c). (d).

Figure 5.4 Unique segments and lined motifs in group 1

- Lower part are unique segment and
- Upper part shows their lines

In order to get a first quarter of the motif first we will generate component in figure 5.3 on the canvas, after that move backward to the left hand side to generate a component is shown in figure 5.5.b which is a lined motif of *Dokjik's diamond*, and then follow by a lined motif of *Naga head* in figure 5.5.a. A result after generating three lined motifs is shown in figure 5.7. If we look back to the photo, the lined motif of *Naga head* is a component to determine a height of the desired motif where at the end of the line needs a little edit, figure 5.8 was an output of adjustment.

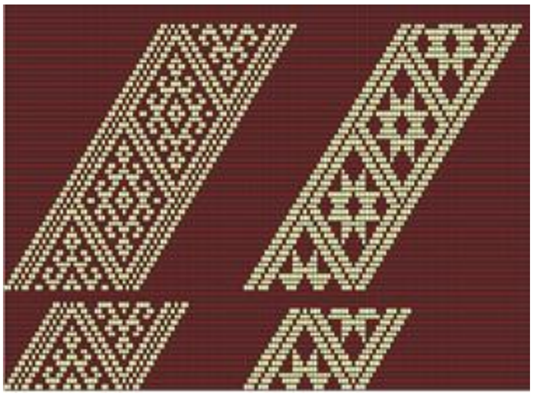


(a). (b).

Figure 5.5 Unique segments and lined motifs in group 2

a. A lined motif of *Naga head* (segment's size:16 x 47).

b. A lined motif of *Dokjik's diamond* (segment's size: 10 x 40).



(a). (b).

Figure 5.6 Unique segments and lined motifs in group 3

a. A lined motif of *Dokkoud*'s *diamond* (segment's size: 14 x 53).

b. A lined motif of *Dokdao's diamond* (segment's size: 14 x 48)

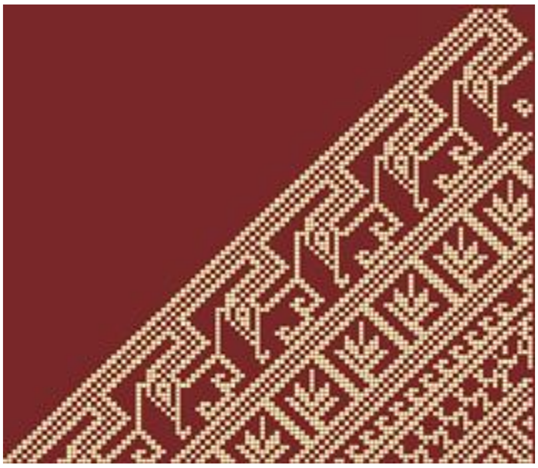


Figure. 5.7
A result after adding the line of *Naga head*

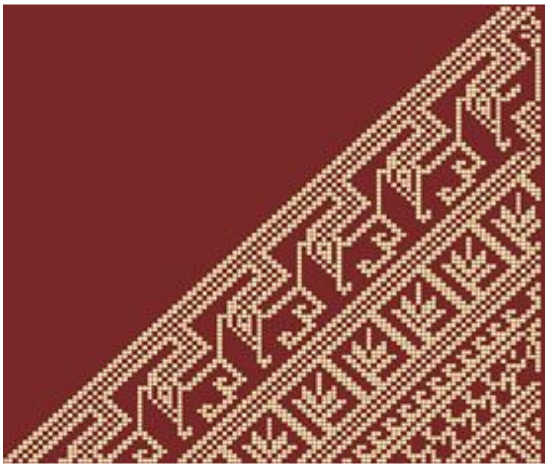


Figure. 5.8
A result after adjusted the line of *Naga head*

We keep adding lined motifs from the order: figure 5.4.b, figure 5.4.a, figure 5.4.c, figure 5.6.a respectively, a corresponding result illustrated in figure 5.9. At this point we reach to a component that indicates a width of the motif; in this step we precisely know a size of the desired motif. However, we continuously put more elements to diagonal empty area in order to get a first quarter segment that looks the same as the original motif. Thus, we continue adding lined motifs from this sequence: figure 5.4.c, figure 5.4.a, figure 5.4.b, figure 5.6.b, figure 5.4.b, figure 5.4.a, figure 5.4.c and finally figure 5.4.a. A result after adding is a complete first quarter of the motif is shown in figure 5.10.

Figure. 5.9
A first quarter of the desired motif with an empty diagonal space (size: 102 x 173)

Figure.5.10
A first quarter of the desired motif after filling corresponding lines to the empty space

In order to get a complete motif we need two symmetry operations, first operation is to copy and apply vertical reflection of the segment, from this step we got first half of the motif is shown in figure 5.11, and then the second operation is to copy and apply horizontal reflection to the first half of the motif, finally we get a complete symmetric motif is shown in figure 5. 12.

Figure. 5.11
A result of a first half's motif after operating its first quarter's segment (size: 203 x 173)

Figure 5.12
A complete desired motif after generating its second half segment (size 203 x 345)

This experiment obviously shows how simple to create lined and single motifs by using the LT-Tieup module. Generating each lined motif requires small unique segment, but we can get a line as long as we want. A length of each line depends on a canvas's width. The unique segments must be designed on or added to the canvas of the LT-Tieup module before we apply an operation to generate the lined motifs. Moreover, the result of this experiment also shows how simple to generate a big hierarchical motif. The generation takes few steps and mainly applies symmetry operations. Once we have few lined motifs, then we are able to generate various hierarchical motifs by a random combination of the lined motifs. Regarding traditional Lao style, the LT-Tieup module provides some predefined lined motifs which are common found on Lao traditional textiles. This facility helps us to easily generate a variety of lined motifs in minutes by just selecting a motif's segment from a list and defining a length of line. In the following section we will focus on an experiment to generate single motifs by using geometry's structure of the cyclic and dihedral groups.

5.1.3 Generating Single Motifs

The motif generated by a combination of lined motifs above is one example of using symmetry operations for generating motifs. In this section we consider the creation single motifs. To create single motifs by the LT-Tieup module we use predefined motifs together with symmetry operations. The design method is dependent on the motif structure e.g., the creation of motifs using the cyclic group or motifs from dihedral group. Since cyclic group and dihedral group are mathematical concept for finite design that are suitable for creating a big motif for Lao textile style. Usually before producing any motif we have to define a unique segment of the motif. After that we apply symmetry operations, the only exception being motifs from the *c1* group, which are missing any symmetry. Therefore, we have to provide a unique segment of the desired group to the LT-Tieup module; otherwise the module will not generate any motif. We should know the characteristics of the required segment in each group where they were already described in chapter 3. A motif of *c2* group is applied two rotation orders while a motif of *c4* group applied four rotation orders. A motif of *d1* group is applied only reflection no rotation or its rotation order is only one. A motif of *d2* group contains two reflections and two rotation orders. Definitely, a motif of *d4* group contains four reflections and four rotation orders. As a result, the experiment follows those characteristics to define unique segment and to generate a motif for each group.

The restriction on woven design causes to limit number of motif style of cyclic and dihedral groups. The most styles found on Lao textile are *c1*, *d1* and *d2*. We use predefined motifs provided in the LT-Tieup module as unique segment for testing each group. However, *d4* group is a new style for Lao textile; we need to define its motif's segment by ourselves. The generation's results with their description for each group are presented below:

Generating motifs of cyclic group

Motif name:	*Small Lion*
Item type:	found on Tai Daeng Ethnic Sihn
Source:	Phaeng Mai gallery, Vientiane capital

A motif of *small Lion* is referred as an original motif for generating motifs of the cyclic group. Their generation's results are presented in figure 5.13 while figure 5.13.a shows a photo of the original motif that was taken from Phaeng Mai gallery in Vientiane capital. The motif was found on a Sihn of Tai Daeng ethnic. A motif of *c2* group is presented in figure 5.13.b, due to this group contains two rotation orders, so the required segment for this group is a segment of first rotation order. A motif of *c4* group is presented in figure 5.13.c, a motif of this group contains four rotation orders that mean a design area of the required segment is only in the first quarter of the motif.

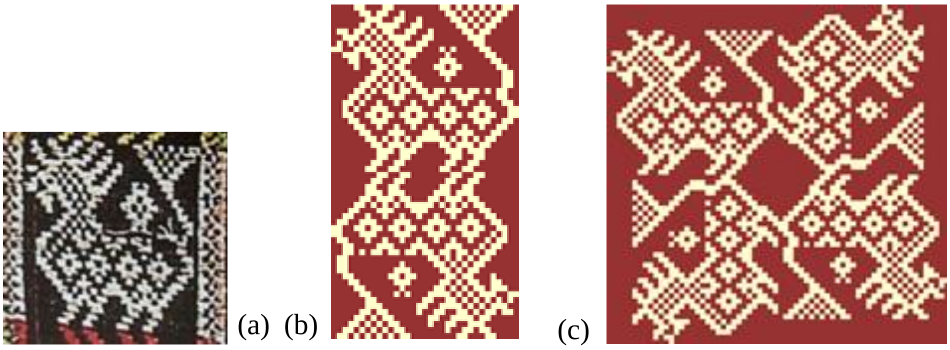

(a) (b) (c)

Figure 5.13 Motifs of *cyclic* group

a. A photo of an original *small Lion* motif
b. A digital motif of *c2* group generated by the LT-Tieup module
c. A digital motif of *c4* group generated by the LT-Tieup module

Generating motifs of dihedral group

Motif name: *Boa snake's skin*
Item type: found on Tai Daeng Ethnic Sihn
Source: Book "Sihn and Lao Women"

To generate *d1* and *d2* of the dihedral group we use a motif of *Boa snake's skin* that found on a Sihn of Tai Daeng ethnic. Figure 5.14.a shows a photo of original *Boa snake's skin* motif. A digital motif of *d1* group is shown in figure 5.14.c, it contains only one reflection and no rotation, this group is similar idea to *c2* group, but instead of containing rotation orders this group contains reflection. A required segment is a first segment of the reflection that illustrated in figure 5.14.b. A digital motif of *d2* group is illustrated in figure 5.13.d; this group contains two rotation orders and two reflections that mean a design area of the required segment is only in the first quarter of an axis. A motif of *d4* group contains four rotation orders and four reflections that mean a design area of the required segment is only in the first half diagonal of the first quarter of an axis. Figure 5.15.a illustrates a required segment for testing the *d4* group and figure 5.15.b illustrates generation's result which is generated by the LT-Tieup module.

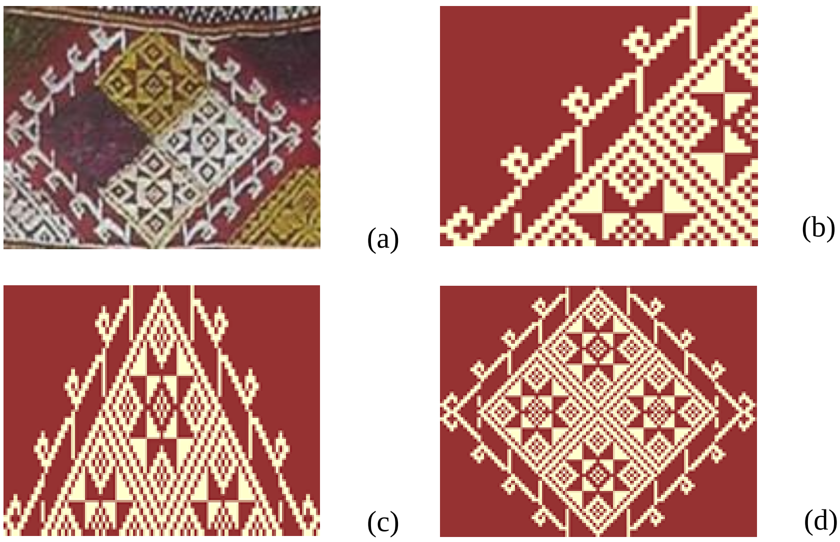


Figure 5.14 Motifs of *d1* and *d2* groups

a. A photo of an original *Boa snake's skin* motif
b. A required segment for the dihedral group that generated by the LT-Tieup module
c. A digital motif of *d1* group generated by the LT-Tieup module
d. A digital motif of *d2* group generated by the LT-Tieup module

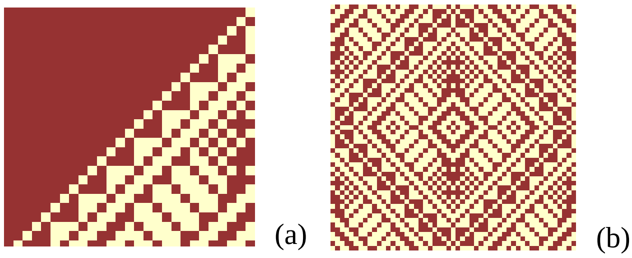


Figure 5.15 A motif of *d4* group

a. A required segment for *d4* group that generated by the LT-Tieup module
b. A digital motif of *d4* group that generated by the LT-Tieup module

The experiment in this section shows additional ability of the LT-Tieup module to generate single motifs. Because the digital motifs were generated by based on geometry's structure of the cyclic and dihedral groups, the required segment was a key to generate their motifs. On the canvas of the LT-Tieup module, we must have in mind that which motif we want to generate, then we define a motif's segment. The segment will be an input to apply an operation for motif's generation on the LT-Tieup module. We found that getting correctly desired motifs by this approach is simple and quick if we define a proper motif's segment.

5.1.4 Extracting Motifs from Images

Motif name:	*Cab with hooks*
Item type:	Tai Moy Ethnic Sihn, Huaphanh province
Source:	Book "Legends in the Weaving"

The main idea for extracting motif is to get binary images from photos for using them as input single motifs to the LT-Tieup module. The image processing library developed by A. Kirillov [1] (developed in C# programming language) is used as a tool to perform the experiment. The experiment aims to investigate possible techniques for extracting traditional Lao motifs, so we take motif's samples from traditional antique textiles. The samples represent three different groups of motifs. Firstly, it is a group of motifs with simple structure and the motifs are decorated with one weft (single-color motifs). Secondly, it is a group of motifs with simple structure, but they are decorated with multiple wefts (multi-color motifs). The last group is a group of motifs with complex structure, but they are decorated with one weft (single-color motifs). A list of the samples and details of techniques used in each photo is shown in table 5.1.

The experiment follows three steps that introduced in chapter 3 (see page 50), while the use of techniques in each step is various due to a resolution of the photos. Contrast enhancement is a first step of extracting motif, but it depends on intensity and color of motif (foreground). If motif's color is brighter than its background, then we can skip a process of contrast adjustment. We directly convert the photo to grayscale image and then move to a process of image binarization. In table 5.1 illustrates that only 60% of the samples applied contrast enhancement.

Image . No	Image's Size	Contrast	Threshold before filtering	No. using median filter	No. using adaptive filter	Threshold after filtering	Morpholo-gy
1	300 x 192	2	70	1	2	150	Closing, Opening
2	302 x 248		100	3	4	150	Closing, dilation, closing
3	74 x 106		180	1	2	150	
4	502 x 446		100	4	2	90	
5	502 x 324		100	1	2	90	
6	152 x 232		100	1	2	90	
7	502 x 324		200	1	3	150	Opening
8	276 x 180	2	150	1	1	150	Closing
9	314 x 272	5	220	1	2	150	
10	486 x 326	2	140	1	2	90	Closing
11	112 x 189	3	140	1	1	150	
12	200 x 268	1.5	140	1	1	150	Closing
13	520 x 198	2	90	1	1	150	
14	396 x 162	1.25	50	1	2	150	Closing
15	500 x 270		220	1	2	150	Closing
16	290 x 190	1.5	180	1	1	150	Opening , Closing

Table 5.1
List of image processing techniques use to operate the photos

In step of image binarization, we apply thresholding technique with a definition that black is foreground and white is background. If threshold's value is low, it means increasing black pixels to a binary mage. In contrast, if threshold's value is high, it means reducing black pixels from (or increasing white pixels to) the binary mage. Regarding experiment, we define threshold's value twice, the first is threshold's value for binarization before filtering and the second is threshold's value for binarization after filtering. We found that if motif's photos are dark and motif's structures are complicated then the threshold's value must be low in order to detect a shape of the motif; their threshold's values before filtering are set in between 50-100 and their threshold's values after filtering are set to 90. However, if the photos are normal and motif's structures are simple then their threshold's values before filtering are set in between 140-220 and their threshold's values after filtering are set to 150.
In the last step of the experiment, morphological operations are mainly used for noise removal while mean, median and adaptive filters are mainly used for edge adjustment. From the samples, we found only three morphological operations; they are close, open and dilation while the close operation is the most morphology used. In order to explore better results, we categorize the filtering techniques into three cases, the first

case is filtering by mean filter; the second case is filtering by median filter; and the last case is filtering by adaptive filter. In terms of image, each case produces good results, because from binary images we still see motif's figure. However, in terms of weft-face pattern-weave the results are not good pattern-drafts, because the shapes of motifs that formed by black pixels are not well arrangement. Regarding characteristic of Lao motif, the motif contains composite structure; motif's element in each layer is arranged in only three possible directions namely horizontal, vertical and diagonal. Therefore, it is impossible to get precise structure from input photos; the filtering outputs from three cases provide only overall structure. In order to get motif's structure like traditional Lao style, the outputs still have to be modified a lot by the LT-Tieup module. We found that if we need to detect motif's detail as much as possible then the mean filter is the most suitable technique and the second technique is the adaptive filter. The median filter is suitable used when the motif's structure is simple and the motif's element in each layer is not close to each other; if motif's structure is complicated and each layer is tiny then median filter is not suitable technique. On average, the mean filter gives better outputs than the median and adaptive filters.

Figure 5.16
A photo of *cab* motif with size (290 x 190)

Figure 5.17
A digital *cab* motif generated by the LT-Tieup module, size (81 x 65).

Filter Sequence 1:	Filter Sequence 2:	Filter Sequence 3:
- Contrast 1.5 - Grayscale - Threshold 180 - Morphology: opening - Invert - Mean Filter - Threshold 150 - Morphology: closing	- Contrast 1.5 - Grayscale - Threshold 180 - Morphology: opening - Invert - Median Filter	- Contrast 1.5 - Grayscale - Threshold 180 - Morphology: opening - Adaptive Filter (1) - Threshold 150 - Invert

Table 5.2
Morphological operations results

To evaluate this approach, we compare as an example filtering sequence 1, 2 and 3. A list of the sequences illustrates in table 5.2, the sequences are used to operate a photo of *crab* motif that is shown in figure 5.16. Figure 5.17 shows a digital *crab* motif that is generated by the LT-Tieup module. A photo's size is 290x190 pixels, but a size of the digital motif is 81x65 pixels, because we follow original motif's design. The motif has single color, it is symmetric and its structure is simple. We can say that this motif is a composite symbol with three layers; the first layer is parallel diagonal lines with big hooks; the second layer is a group of small hooks and rhombuses that are arranged in diagonal direction; the last layer is a diamond shape. To compare the results to the original design, we use the digital *crab* motif in figure 5.17 to represent the original design. We shrink a size of binary images by factor of two with using nearest neighbor interpolation, then taking only their quarter segment. The result of each sequence is illustrated from figure 5.18 to figure 5.20; on the left hand side is a binary image of full motif and its quarter segment is on the right hand side.


(a)

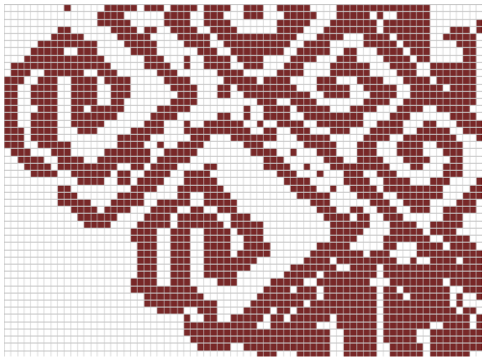
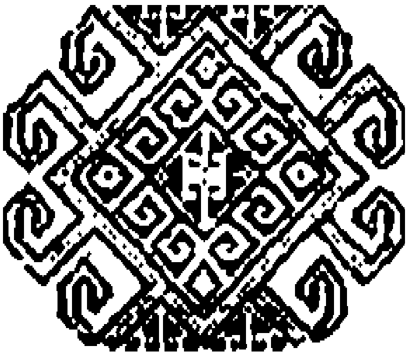

(b)

Figure 5.18 Extracting's result by filter sequence 1

a. Result of binary image from Filter sequence 1, size (290 x 190)
b. A quarter of the binary image imported to the LT-Tieup module (73x49)


(a)

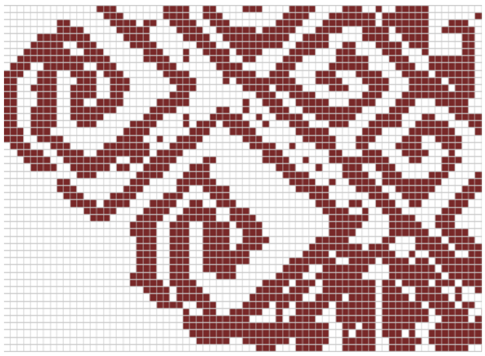
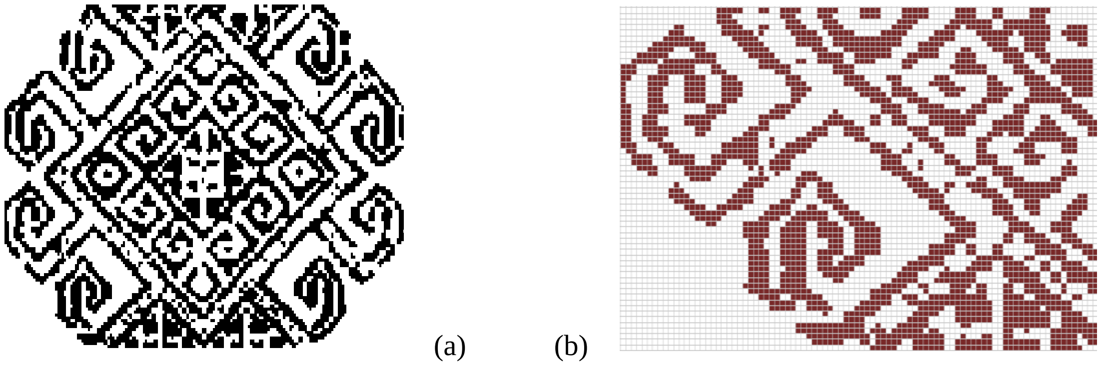

(b)

Figure 5.19 Extracting's result by filter sequence 2

a. Result of binary image from Filter sequence 2, size (290 x 190)
b. A quarter of the binary image imported to the LT-Tieup module, size (73 x 48)



(a) (b)

Figure 5.20 Extracting's result by filter sequence 3

a. Result of Binary image from Filter sequence 3, size (290 x 190)
b. A quarter of the binary image imported to the LT-Tieup module, size (73 x 49)

If we compare the quarter segment of each result to the original design, we would see that their motif's layers are not well arranged. In the first layer, lines are not diagonal; especially a dot line almost disappears. In the second layer, each small hook gets different structure and they are not arranged in diagonal direction as well. However, the filter sequence 1 and filter sequence 2 produce similar results and they are better than a result of filter sequence 3. If we compare layer by layer, we see that the sequence 2 produce better result than other sequences. The digitized motifs from this experiment are ready pattern-drafts for weaving with electronic loom, but it would be difficult task to make their manual pattern-drafts for hand weaving. Due to a complexity of motif's structure, we can only apply image processing techniques to motifs with small and medium sizes. If we compare the approach of image processing to the LT-Tieup module, the module is still a better tool to digitize traditional Lao motifs. Because the module already provides necessary operations to generate all kind of motifs, digitizing small and medium motifs are simple task. Therefore, this experiment only investigates three filtering sequences to observe a better result. Currently, the investigated techniques are able to extract only overall structure of the Lao motif. A deeply investigation on image processing techniques for extracting Lao motif are still opened.

5.1.5 Generating Frieze Patterns

Generating Frieze patterns is similar idea to generating motifs of the cyclic and dihedral groups, a necessary data needs to provide to the module is a unique segment of motif if the segment defined properly then the pattern would be generated correctly. The unique segment needed in each group for the Frieze patterns is shown on the schema in figure 3.4 in chapter 3 (see page 35). Therefore, a position of required segment has to be considered before applying symmetry operations of the LT-Tieup module. Regarding seven symmetry groups of the Frieze group, geometric structure of some groups are similar and in some groups are different. Thus, to show similarity between their pattern styles in some generations we used the same unique segment. Details of the experiment on generating Frieze pattern will be explained as follows.

Generating Frieze patterns of *Hop* group

Motif name: *Bird*
Item type: found on Tai Dam Ethnic Sihn for Wedding
Source: Phaeng Mai gallery, Vientiane capital

A motif for *Hop* group is asymmetric which means a whole motif is a required segment for generating one-directional patterns of the *Hop* group. We use a *Bird* motif for generating this group, figure 5.21.a presents an original *Bird* motif on a Sihn of Tai Dam Ethnic, figure 5.21.b shows its digital motif that generated by the LT-Tieup module and a result is shown in figure 5.21.c

(a)

(b)

(c)

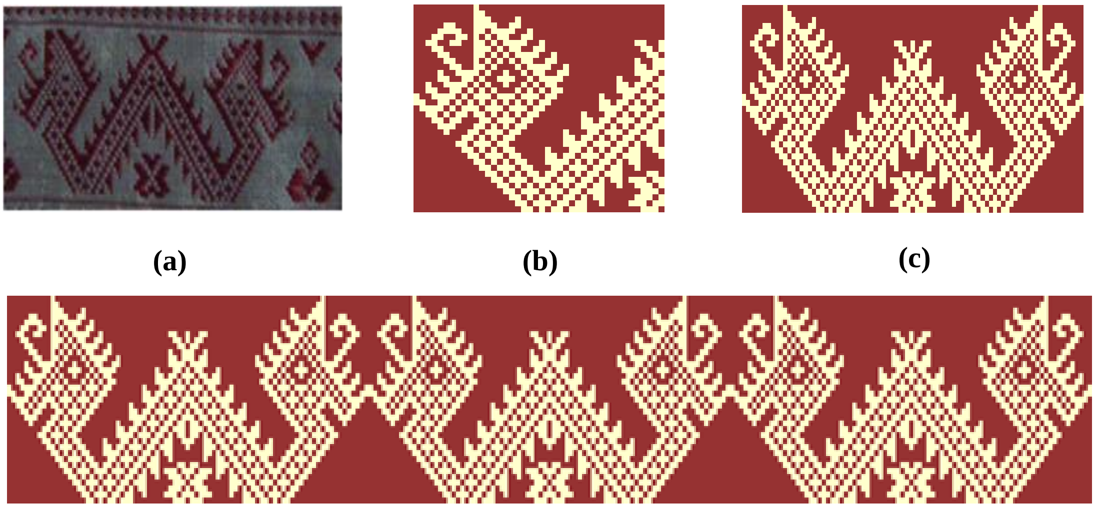
Figure 5.21 Generating a Frieze pattern of *Hop* group

a. A is a photo of an original *Bird* motif on textile
b. A digital *Bird* motif generated by LT-Tieup module
c. A generative Frieze pattern by *Hop* group with repetitive motifs

Generating Frieze patterns of *Sidle* group

Motif name: *Small mating Naga*
Item type: found on a piece of master pattern
Source: Nonsaad village, Vientiane capital

A motif for *Sidle* group is symmetric which contains only vertical reflection, so a required unique segment is a segment on the left hand side of the motif. Therefore, we no need to design a complete motif, but we have to design a first half of vertical reflection, after that when we apply the operation for *Sidle* group the LT-Tieup module will generate a Frieze pattern of *Sidle* group automatic. A motif of *mating Naga* is used as referred motif for this generation; a required segment, a digital motif and a result are illustrated in figure 5.22.



(a) **(b)** **(c)**

(d)

Figure 5.22 Generating a Frieze pattern of *Sidle* group

a. A photo of *mating Naga* on textile
b. A required segment for *mating Naga* motif generated by LT-Tieup module
c. A corresponding motif of defined segment for *Sidle* group
a. A generative Frieze pattern of *sidle* group with three repetitive motifs

Generating Frieze patterns of *Jump* group

Motif name: *Two headed Naga in S shape*
Item type: found on Tai Daeng Ethnic Blanket
Source: Songpeuy village, Vientiane capital

A motif for *Jump* group is symmetric which contains only horizontal reflection, so a required unique segment for this group is similar to *Sidle* group, but instead of using a segment on a vertical left hand side, this group requires a segment on first half of horizontal reflection. So we need to design the segment, before we apply the operation of *Jump* group. To test the generation of this group we used *two-headed Naga* is *S* shape as an original motif, it found on a blanket of Tai Daeng ethnic in Songpeuy village, Vientiane capital. We use the LT-Tieup module to define a required segment and generate a Frieze pattern. Results in each step were illustrated in figure 5.23.


(a)


(b)

(c)


Figure 5.23 Generating a Frieze pattern of *Jump* group

a. A photo of *two-headed Naga* on textile
b. A digital motif generated by LT-Tieup module
c. A generative Frieze pattern of *Jump* group with two repetitive motifs

Generating Frieze patterns of *Step* group: the motif for *Step* group is symmetric which contains only horizontal glide reflection, so a required unique segment for this group is actually the same as the required segment for the *Jump* group. However to a form a motif, after reflection the reflective segment has to translate regards to a given distance. If a given distance equal to zero that means pattern of the *sidle* group is a pattern of the *Jump* group.

Generating Frieze patterns of *Spinning Hop* group: the motif for *Spinning Hop* group contains only two rotation orders; a required unique segment for this group is a first order of the rotation. Actually the geometric principle to construct a motif of this group is the same principle of constructing a motif of *c2* group, but the result of the generation is one-directional patterns. Number of repetitive motifs on the pattern is up to designers, if we define only 1 repetitive motif then the pattern of *Spinning Hop* group become a motif of *c2* group. We use a motif that already defined for *c2* group, see figure 5.13.a and figure5.13.b for the original motif and the digital motif respectively. A result of pattern generation is shown in figure 5.24.

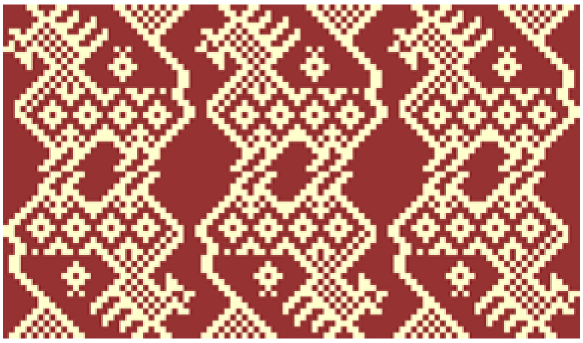


Figure 5.24
A generative Frieze pattern of the *Spinning Hop* group with three repetitive motifs

Generating Frieze patterns of *Spinning Sidle* group: A fundamental parallelogram of the *Spinning Sidle* group consists of two symmetric motifs that arranged in diagonal line. This means that the fundamental parallelogram contains four reflective segments. The first two reflective segments are on the first half of a horizontal glide reflection, called first and second segments; these two segments are vertical mirrored to each other while other two reflective segments are on the second half of the reflection, called third and fourth segments, see more detail on schema in figure 3.4, page 35. Thus, a required unique segment for this group is only the first segment, after that we use an operation of the LT-Tieup module to generate a corresponding pattern. We use an original motif and its required segment from generating *Sidle* group in figure 5.22. A result of generation in each step is shown in figure 5.25.

(a) (b)

Figure 5.25 Generating a Frieze pattern of *Spinning Sidle* group

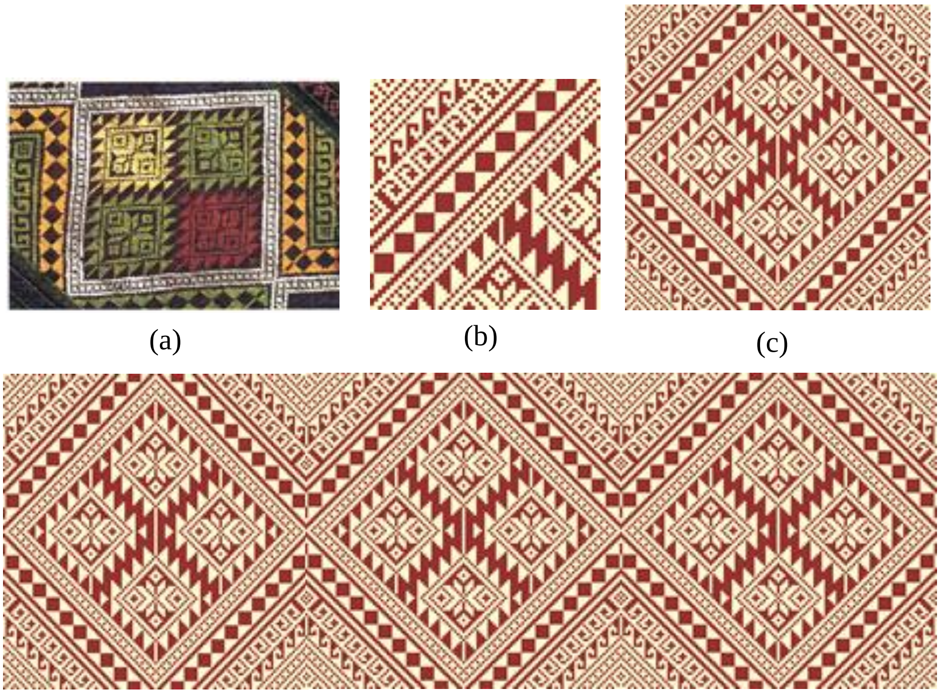
a. A fundamental parallelogram (motif) of *Spinning Sidle* group
b. A generative one-directional pattern with three repetitively motifs of *Spinning Sidle* group

Generating Frieze patterns of *Spinning Jump* group

Motif name: *Square of flowers*
Item type: found on Tai Lue Ethnic Sihn, Oudomxay province
Source: Book “Legends in the Weaving”

To show variety of traditional Lao motif, we use a new motif for testing pattern of *Spinning Jump* group. The original motif was taken from a textile book published by Phaend Maii gallery; it was a motif of *square flowers* (or *diamond of flowers*), it was designed on a Sihn of Tai Lue ethnic. The motif contains vertical and horizontal reflections this means the motif consists of four reflective segments where the first reflective segment on the first quarter is a required segment for generating this group. Results of generation pattern and pattern’s components are illustrated in figure 5.26.

This experiment tested to generate seven styles of Frieze patterns based on geometry’s structures that constructed on the LT-Tieup module. Generating symmetrical patterns is like generating symmetrical motifs, a unique segment is a necessary input to the LT-Tieup module for generating the Frieze patterns. If the segment was properly defined then the patterns would be correctly generated. We found that by using the LT-Tieup module is easy to get a Frieze pattern of seven symmetry groups. Once a unique segment and a number of repeated motifs were defined then a generation's operation will generate a Frieze pattern automatically. With one unique segment we are able to create more than one pattern style.



(a) (b) (c)

(d)

Figure 5.26 Generating a Frieze pattern of *Spinning Jump* group

a. A photo of a *square flower* motif on textile
b. A required segment for generating motif of *Spinning Jump* group
c. A digital motif for *Spinning Jump* group generated by LT-Tieup module
d. A generative Frieze pattern of *Spinning Jump* group with two repetitive motifs in horizontal direction

Two directional patterns are another pattern styles that we are going to experiment in the next section. In chapter 3 we constructed classification diagrams to analyze and classify two-directional patterns by regarding number of rotation order. For experiment on two-directional patterns or wallpaper patterns we also organized the same idea by generating the wallpaper patterns with one rotation order first, after that we generated the patterns with two rotation orders and finally we generated the patterns with four rotation orders. The LT-Tieup module was already constructed the 16 geometric structures of 12 symmetry groups; we need only to define a unique segment to form a motif and to generate a wallpaper pattern. To help more understand and easier to follow explanation; see the schema in each category on page 35-39 for checking and comparing to the results of the experiment. To test all symmetry groups of wallpaper patterns, we selected a variety of motifs and patterns that were common used in design and they were originally collected from traditional Lao textiles. We will start generate the wallpaper patterns in the first category that will be explained as follows.

5.1.6 Generating Wallpaper Patterns in the First Category

In the first category actually there are only four symmetry groups, *cm*, *pm*, *pg* and *p1*, but due to two possible reflections, vertical and horizontal which can be applied to symmetry groups that yield to produce 7 different geometric structures, for more detail please see the diagram in figure 3.6, page 3 37 and the schema in figure 3.7, page 37. The experiment on this category with the detail of their components and their requirements are going to explain as follows.

Generating wallpaper patterns of *cm group*: a fundamental parallelogram of the *cm* group consists of four reflective segments and the geometry of the *cm* group uses only reflection and glide reflection. However, there are two possible reflective directions, vertical and horizontal that cause to have two pattern styles in this group. The first style, its fundamental parallelogram contains vertical reflection and vertical glide reflection denoted by *cm_v*. Similarly, the fundamental parallelogram for the second style contains horizontal reflection and horizontal glide reflection, denoted by *cm_h*. In the case of vertical direction, first two reflective segments are mirrored each other in vertical direction where a segment on the left hand side is our required segment for generation, other two segments are vertical glide reflection of the first two segments. Because the geometric structure of this group is similar to the *Sidle* group, we used a motif of *mating Naga* which its original motif and a required segment were already defined in the section for generating Frieze pattern of the *Sidle* group. A complete two-directional pattern of the *cm_v* group is illustrated in figure 5.27.

(a) (b)

Figure 5.27 Generating a wallpaper pattern of *cm_v group*

a. A fundamental parallelogram of *cm_v* group
b. A generative wallpaper pattern of *cm_v* group with two repetitive motif in two directions

For the case of horizontal direction, first two reflective segments mirror each other in horizontal direction while other two segments are horizontal glide reflection of the first two segments. The required segment is still the same as the first case. To test this case we used a motif of *mating Naga* from the section to generate *Jump* group where the original motif is shown in figure 5.23.a and the required segment presented and figure 5.23.b respectively; a generative wallpaper pattern for this group is shown in figure 5.28.

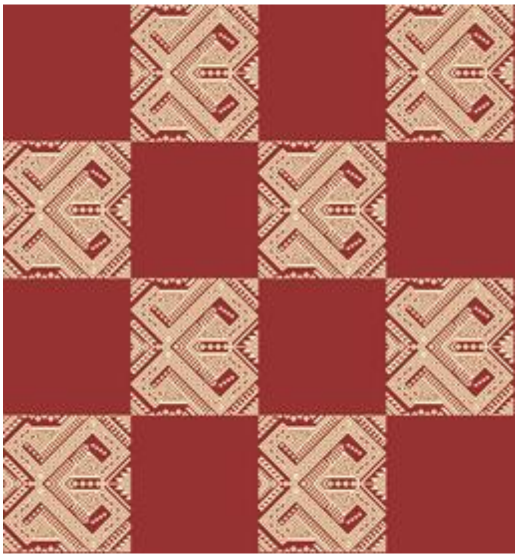

(a)
(b)


Figure 5.28 Generating a wallpaper pattern of *cm_h group*

a. A fundamental parallelogram of *cm_h* group
b. A generative wallpaper pattern of *cm_h* group with two repetitive motif in two directions

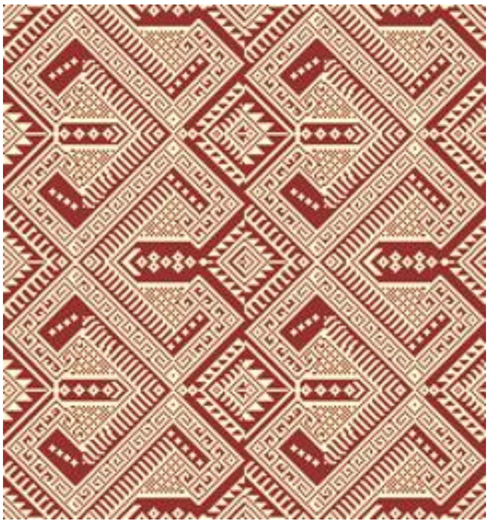


Figure 5.29
A generative wallpaper pattern of *pm_h* group with two repetitive motifs in two directions

Generating wallpaper patterns of *pm group*: Unlike a motif of the *cm* group, a motif of the *pm* group consists of two reflective segments and it contains only reflection, but its reflection can be vertical or horizontal. Therefore, this group can also produce two pattern styles. For the style that applied vertical reflection we denoted by *pm_v* and the style that applied horizontal reflection we denoted by *pm_h*, a required segment for those two styles is a first half of reflection. To test variant possibility on pattern generation we keep using a motif of *mating Naga*, from testing the groups *sidle*, *spinning sidle* and *cm_v* for testing the *pm_v* group. For the second case we create a motif from testing the *Jump* group. A generation's result from testing *pm_h* is presented in figure 5.29 while a generation's result for *pm_v* is is shown in figure 5.30.

Figure 5.30
A generative two-directional pattern of *pm_v* group

Generating wallpaper patterns of *pg group*: according to the analysis result on Lao patterns from our field trips, we have not found the *pg* group in any samples. Therefore, we have to design a new motif and define its unique segment by ourselves in order to introduce this new pattern style to Lao weavers. We use the predefined *small Siho* motif as a required segment. To show the similarity between pattern styles, we use the same segment for testing these two pattern styles. From the results is illustrated in figure 5.31 and figure 5.32, we can clearly see the similarity between them. If we look at their motifs in figure 5.31.a and figure 5.32.a, the motifs are fundamental parallelograms of them. The motif of the *pg_v* group contains horizontal glide reflection while the motif of the *pg_h* group contains vertical glide reflection.

(a)   (b)

Figure 5.31 Generating a wallpaper pattern of *pg_v group*

a. A generative motif for *pg_v* group
b. A generative Frieze pattern of *pg_v* group

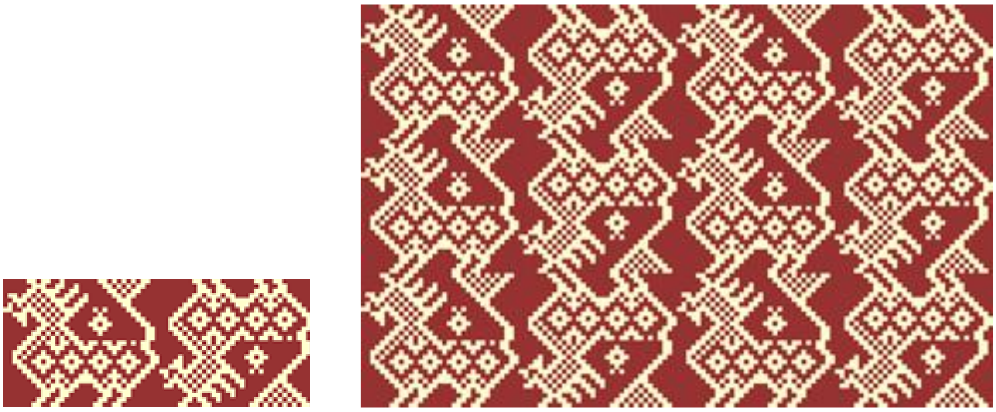
(a)  (b)

Figure 5.32 Generating a wallpaper pattern of *pg_h group*

a. A generative motif for *pg_h* group by LT_Tieup module
b. A generative wallpaper pattern for *pg_h* group

Generating wallpaper patterns of *p1 group*: wallpaper patterns of the *p1* group apply only translation, a motif is a unique segment which does not contain any rotation and any reflection. Actually, the patterns of the *p1* group are two-directional patterns of the *Hop* group, if we define number of repeat motif either in horizontal or vertical direction equal to one, the patterns of *p1* group will become patterns of *Hop* group. Therefore, we use motif of *Bird* to digitize pattern of this group, see figure 5.33 for generation's result.

Figure 5.33
A wallpaper pattern of *p1* group generated by the LT-Tieup module

5.1.7 Generating Wallpaper Patterns in the Second Category

We move the experiment to the second category of wallpaper patterns which is their motifs contain two orders (2-folds) rotation and normally there are five symmetry groups in the category namely *pmm*, *cmm*, *pmg*, *pgg* and *p2*. However, after we apply two possible reflections to the groups, totally we get 6 different geometric structures. For more detail please see the diagram in figure 3.8 and the schema in figure 3.9 on page 38. The experiment on this category with the detail of their components and their requirements will be explained as follows.

Generating wallpaper patterns of *pmm* group: a motif of the *pmm group* contains vertical and horizontal reflections; a first segment of a first half's horizontal reflection is a required segment for this group. Actually, the patterns of the *pmm* group are two-directional patterns of the *Spinning Jump* group. Because the *pmm group* is the most common used in Lao textile decoration, to experiment this group we use a pattern of *square of flowers* which is a popular design and often found on Lao textiles. The generation's result is shown in figure 5.34.

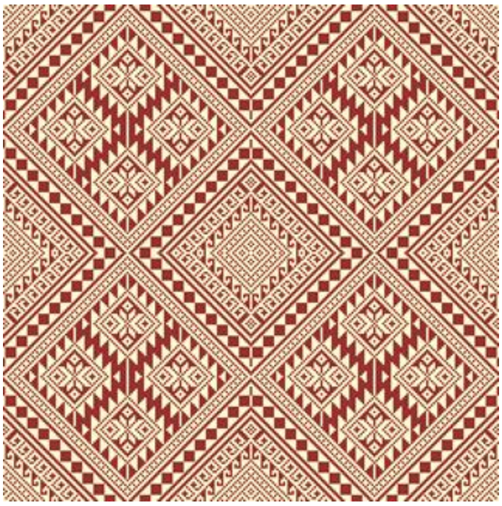


Figure 5.34
A generative wallpaper pattern of *pmm* group with repetitive motifs in two directions

Generating wallpaper patterns of *cmm* group: a fundamental parallelogram of the *cmm* group contains vertical, horizontal and glide reflections. This group expands geometric structure of the *pmm* group by including glide reflection; please see their similarity on the schema in figure 3.9 (page 38). This means both two groups used the same unique segment. However, to show variety of Lao motifs, we use the motif of *Boa snake's skin* for testing the generation of this group. A required segment generated by the LT-Tieup module is illustrated in figure 5.35.a. The corresponding fundamental parallelogram and generation's result are presented in figure 5.35.b and figure 5.35.c respectively.

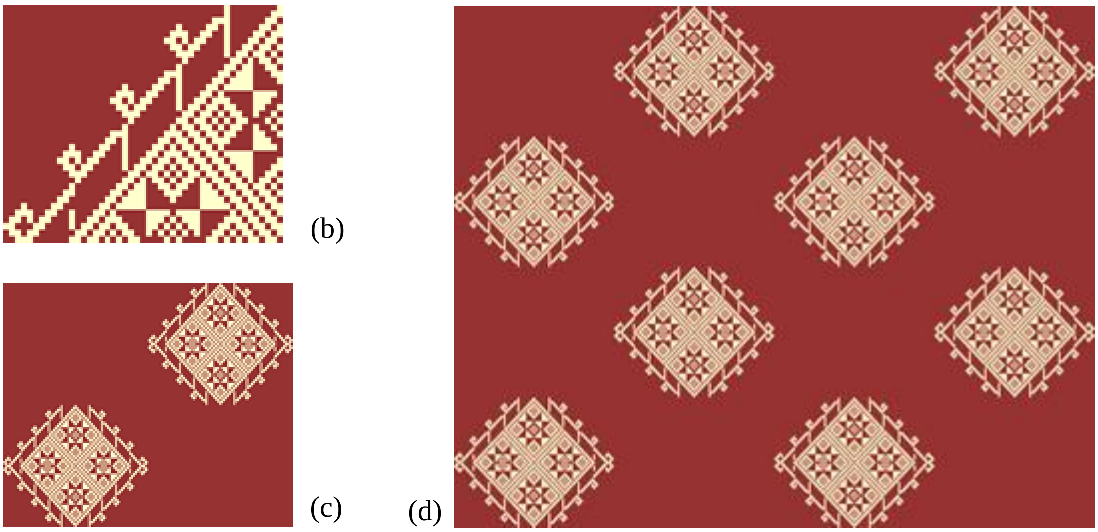


Figure 5.35 Generating a wallpaper pattern of *cmm* group

a. A required segment for generating motif of *cmm* group
b. A fundamental parallelogram of *cmm* group generated
c. A generative wallpaper pattern of *cmm* group with two repetitive motifs in two directions

Generating wallpaper patterns of *pgg group*: a geometric structure of the *pgg* group applies two orders rotation to construct first two segments, after that it applies vertical glide reflection to form a fundamental parallelogram of the group. A required segment for the generation is a first half of rotation. Due to this group produces similar output to the *Spinning Hop* group, so we use a motif of *small Siho* in order to show a similarity between these symmetry groups. Figure 5.36.a illustrates the fundamental parallelogram that contains two symmetric motifs and they are arranged in diagonal direction. The corresponding wallpaper pattern is shown in figure 5.36.b.

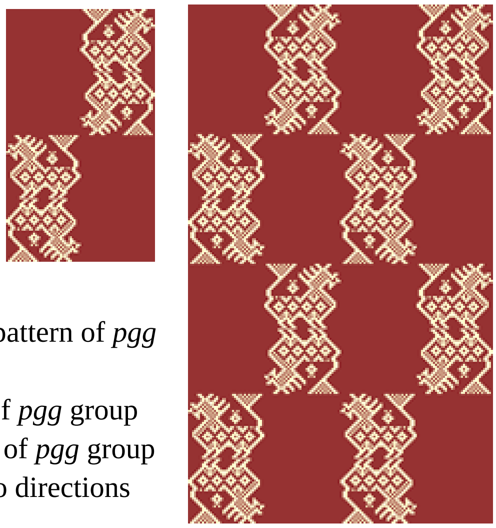


Figure 5.36 Generating a wallpaper pattern of *pgg* group

a. A fundamental parallelogram of *pgg* group
b. A generative wallpaper pattern of *pgg* group with two repetitive motif in two directions

Generating wallpaper patterns of *pmg group*: in the second category of pattern classification, the *pmg* group is only the group that is able to apply either vertical or horizontal reflection which causes to have two available geometric structures. We denoted *pmg_v* for applying vertical reflection. The motif contains four segments where its first two segments are horizontal rotations and other two segments are vertical reflective segments. Similarly, *pmg_h* is denoted for applying horizontal reflection, its motif contains four segments as well, but its first two segments are vertical rotations while other two segments are horizontal reflective segments**.** Because the analysis revealed that this group has not found from textile samples, so in this section we use predefined motif as a required segment. Their generation's results are illustrated in figure 5.37 and figure 5.38.

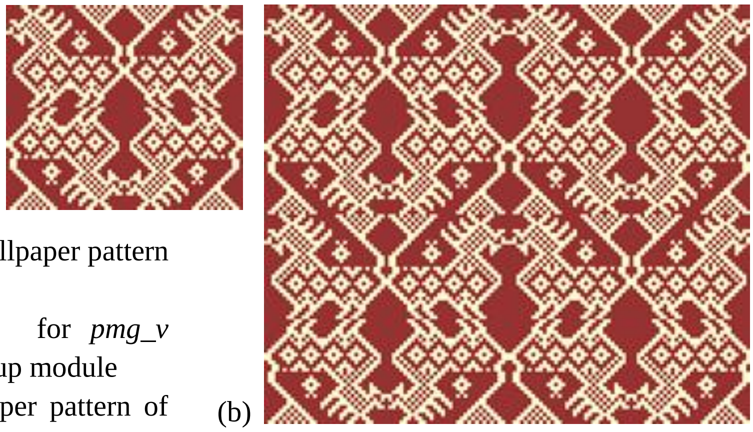


Figure 5.37 Generating a wallpaper pattern of *pmg_v* group

a. A generative motif for *pmg_v* group by the LT-Tieup module
b. A generative wallpaper pattern of *pmg_v* group with two repetitive

(a)

Figure 5.38 Generating a wallpaper pattern of *pmg_h* group

a. A generative motif for *pmg_h* group by LT-Tieup module
b. A generative wallpaper pattern of *pmg_h* group with two repetitive motifs in two directions

(b)

Generating Wallpaper Patterns of *p2 group*: patterns of *p2* group are two-directional patterns of the *Spinning Hop* group while their motifs are motifs of the *c2* group. Therefore, a geometric structure of the *p2* group is less complicated than the other groups in the same category, because its motif contains only two ordered rotation. A required segment is a first segment of the rotation. A generation's result of this group is illustrated in figure 5.39; it shows another possibility for using a given segment (a motif of *small Siho*) to generate a wallpaper pattern.

(a)  (b)

Figure 5.39 Generating a wallpaper pattern of *p2* group

a. A generative motif for *p2* group by LT-Tieup module
b. A generative wallpaper pattern for *p2* group with three repetitive motif in horizontal direction and two repetitive motifs in vertical direction

5.1.8 Generating Wallpaper Patterns in the Third Category

The last category of wallpaper patterns has only three belonging symmetry groups; they are *p4*, *p4m* and *p4g* groups. Their classification diagram and their schema are illustrated in figure 3.10 and figure 3.11 on page 39 respectively. Geometric structures of the symmetry groups in the category are more complicated than other categories.

Generating wallpaper patterns of *p4 group*

Motif name: *Butterfly*
Item type: found on a piece of master pattern
Source: Nonsaad village, Vientiane capital

If we look at the schema, the *p4* group applies only rotation where its motif consists of four segments. We also found that a wallpaper pattern of the *p4* group is actually a two-directional pattern of a motif generated by the *c4* group. We use a predefined motif of *butterfly* for testing this group; the photo of the original motif is shown in figure 5.40.a. A required segment is exactly the *butterfly* motif, so a generative motif of this group is four orders rotation of the *butterfly* motif. The generation's result is presented in figure 5.40.b and a generative wallpaper pattern is illustrated in figure 5.40.c.

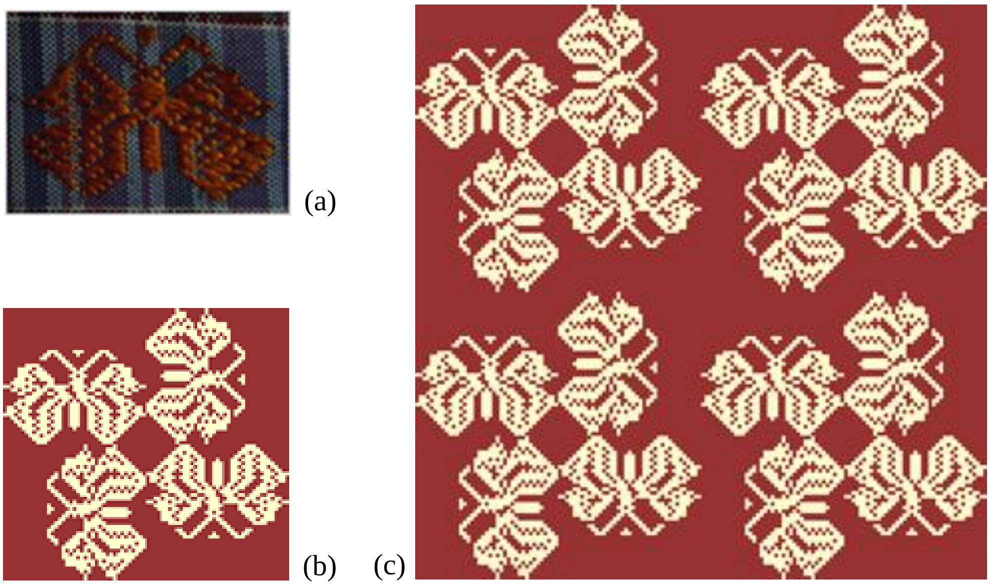


Figure 5.40 Generating a wallpaper pattern of *p4* group

a. A photo of *butterfly* motif on textile
b. A digital motif for *the p4* group generated by the LT-Tieup module
c. A generative wallpaper pattern with two repetitive motifs in two directions

Generating wallpaper patterns of *p4m group*: for the *p4m* group, it applies diagonal, vertical and horizontal reflections; a first quarter of its motif contains two diagonal reflective segments while others quarters of the motif are mirrored segments of the previous continually quarter. A required segment is a first segment of the diagonal reflection. To test this group we define a segment of *leaf* motif that is shown in figure 5.41.a, its corresponding motif is shown in figure 5.41.b and the generation's result is shown in figure 5.41.c.

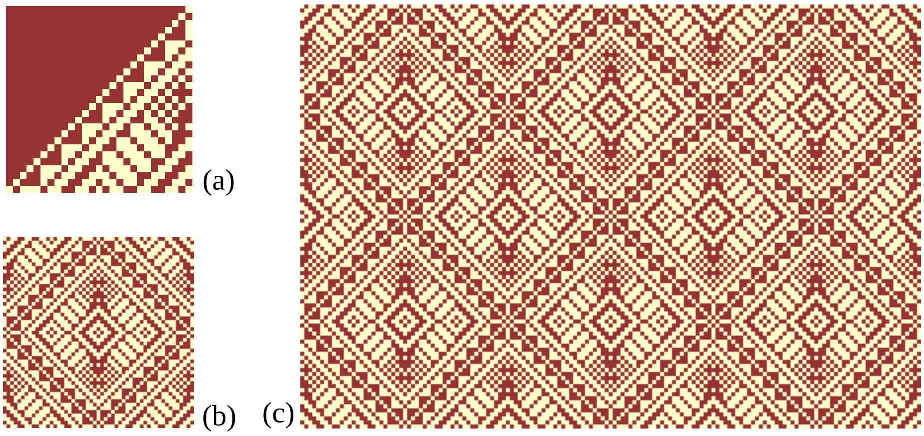


Figure 5.41
A digital wallpaper pattern of *p4m* group generated by the LT-Tieup module

Generating wallpaper patterns of *p4g* group: for the *p4g* group, its geometry is similar to the geometric structure of the *p4m* group; the group applies diagonal reflection and rotation. One more similarity to the *p4m* group is a first quarter of its motif contains two diagonal reflective segments while others quarters of the motif are rotary segments of the previous continually quarter. Definitely, a required segment is the first segment of the diagonal reflection. Thus, we use the same segment of previous generation as showed in figure 5.42.a, a complete generative motif is shown in figure 5.42.b and the generation's result is shown in figure 5.42.c.

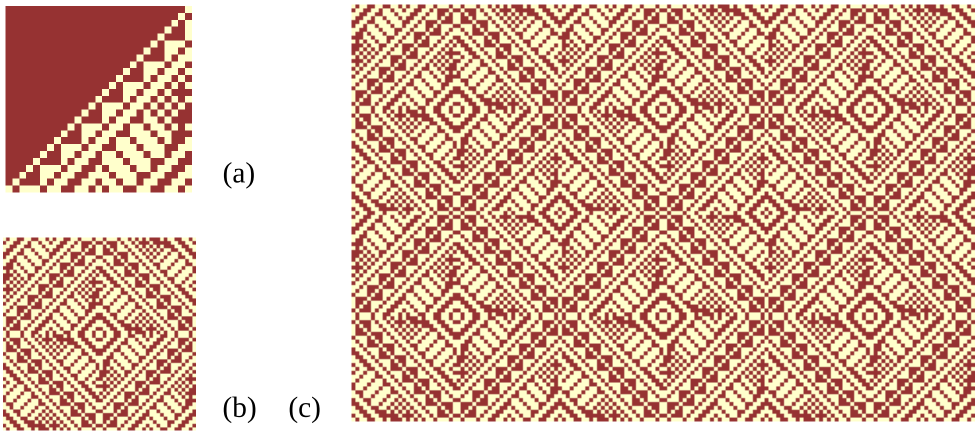


Figure 5.42
A digital wallpaper pattern of *p4g* group generated by the LT-Tieup module

Generating the wallpaper patterns is similar process to generate the Frieze patterns. We found that a wallpaper group provides more ability to generate patterns than a Frieze group. We totally tested 16 pattern styles of the wallpaper patterns by using the LT-Tieup module. We saw that with the same unique segment we were able to create more than one pattern style. The results in this experiment show additional useful of the LT-Tieup module for generating wallpaper patterns. Without using predefined motifs, the generation takes minutes to define a unique segment. However, once the definition is done and numbers of repeated motifs in two directions are defined then a generation's operation will automatically generate a wallpaper pattern. In conclusion, generating the wallpaper patterns for woven textiles by the LT-Tieup module is fast and simple. The common requirements are only a unique segment for each symmetry group and numbers of repeated motifs in two directions.

The LT-Tieup module facilitates pattern generation, but for pattern modification, it takes longer when compare to the LT-Weave module. Therefore, in the next section we will experiment pattern generation and pattern modification by using the LT-Weave module.

5.1.9 Pattern Generation and Modification by the LT-Weave module

Motif name: *diamond flower*
Item type: found on a narrow shawl (Pha Bieng)
Source: Textile shop, Vientiane capital

In this section we will test pattern generation and modification by using the LT-Weave module. The pattern's sample for this experiment is a pattern of *diamond flower* that found on a narrow shawl in textile shop in Vientiane capital, Laos. Before we start the experiment, let we briefly review a structure of the LT-Weave module. The LT-Weave module consists of four design elements that facilitate for generation and modification. Unlike the LT-Tieup module, to generate any pattern by this module is necessary to define values to each element and it is necessary for designers to understand what is element used for; please see the graphical representation of the LT-Weave module in figure 4.7 in chapter 4. We will start from the Tieup element, it is used to design a motif or a unique segment of motif, normally the design on this element must be asymmetrical segment, after that we need to define a sequence on the Threading and Treadling elements for generating a symmetrical motif. If on the Threading and Treadling contain one repeat sequence that mean generating a motif; if we assign multiple repetitive sequence on either the Threading or the Treadling, it means we generate a one-directional pattern; if there are multiple repetitive sequence on both the Threading and Treadling mean to create a two-directional pattern. As a result, creating a new design on this module is very flexible, because a pattern is generated by a combination of three elements, if there is any change in each element that means we get a new pattern. Therefore, creating a pattern on the LT-Weave module needs more imagination than creating a pattern by using symmetry groups in the LT-Tieup module. According to the flexibility on the pattern elements, the LT-Weave module is useful not only for generating patterns, but it is a suitable tool for modifying existing patterns as well.

To experiment on pattern generation we use a pattern of *diamond flower* as a referred pattern is shown in figure 5.43.a, and then we define a unique segment on the Tieup element in figure 5.43.b. First we test the module to generate a motif of the pattern by defining only one repeat symmetrical sequence on the Threading and

Treadling elements. The next step we test the module to create a one-directional pattern which is a pattern of the *spinning jump* group, by assigning two repetitive symmetrical sequences on the Threading element. We keep experiment on generating two-directional pattern by assigning two repetitive symmetrical sequences on the Treadling element. The final result is a two-directional pattern of the *pmm* group, see figure 5.43.e.

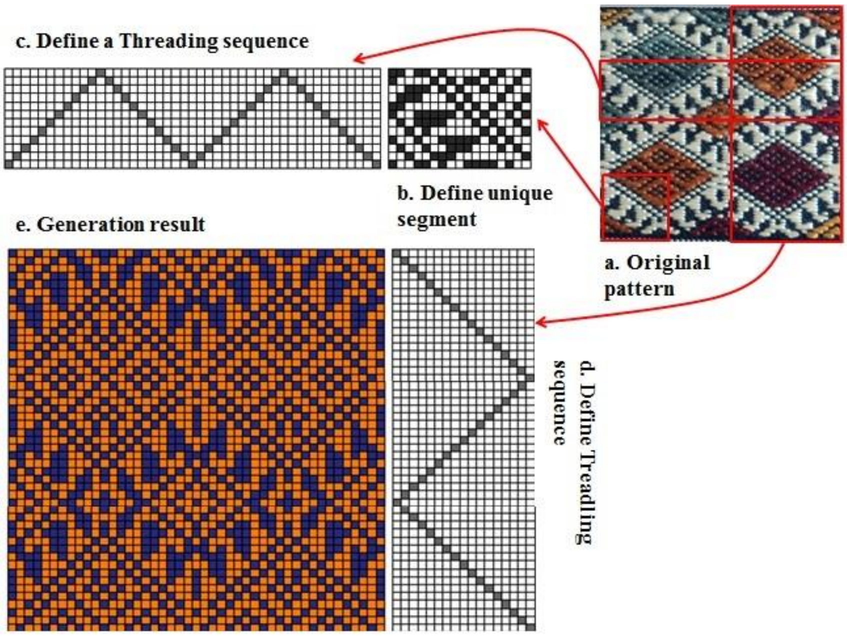


Figure 5.43
Design a pattern of *diamond flower* on the LT-Weave module

To experiment simplicity and flexibility on pattern modification, we use the two-directional pattern in figure 5.43 to modify in three cases. In the first case, we changed only the design on the Tieup element, a result definitely changed the appearance of the motif, but geometric structure of the pattern is still the same. In the second case, we changed the sequence on the Threading element, but other elements keep the same setting. Obviously, the geometric structure of the pattern on a horizontal direction was changed that produces a new pattern style. In the final case, we just change the sequence on the Treadling element that causes the appearance of the pattern on vertical direction changed. These modifications are three examples of various cases for pattern modification on the LT-Weave module. They show how simple to modify a pattern on the module. From a given pattern we are able to change to many possible patterns by just changing a few values on its specific elements. Moreover, a visualized result can immediately see on a window of the LT-Weave module. Because of the LT-Design module embedded LT-Tieup module and LT-Weave module, motifs modification and patterns modification on the LT-Design module work the same as we did in the standalone LT-Tieup and LT-Weave modules.

Therefore, we avoid to present redundant experiment by move to present weaving experiment in the next section.

5.1.10 Summary on Digitizing Experiment

We digitize two types of motifs namely lined and single motifs and we digitize two types of patterns that are Frieze and wallpaper patterns. The modules LT-Tieup and LT-Weave are main tools for digitizing. The samples for the experiment mainly are from traditional Lao textiles. We found that digitizing either motifs or patterns always requires a unique segment before generating. To define the segment on the LT-Tieup module, it must be added to or designed on the canvas. On the LT-Weave module, the segment must be imported or designed on the Tieup element. The schemas that present geometric structure of symmetry groups for motif and pattern generations, they are good guidelines to designers for understanding and generating their targets. The experiment also found a relationship between symmetry groups, and between finite design groups and symmetry groups, such as a motif of the cyclic and dihedral groups are elements of the Frieze patterns and wallpaper patterns while the Frieze patterns are elements of the wallpaper patterns.

For digitizing motifs, the LT-Tieup module is a useful tool. It provides symmetry operations for creating symmetric motifs, generation's operations for creating motifs of the cyclic and dihedral groups. The LT-Tieup module also provides predefined motifs to speed up design process and to support traditional Lao style. Digitizing each type of motifs took few steps, but we got very interesting motifs that we would see from the experiment's results. The results illustrated how useful and simple of using the LT-Tieup module. For digitizing patterns, the LT-Tieup module provides seven symmetry operations to generate Frieze patterns and 16 symmetry operations to generate wallpaper patterns. These operations speed up generation process and facilitate designers to easily generate their own patterns. By using the same unique segment the designers are able to get different patterns, in the experiment we used the same segment to show similarity between patterns. The experiment's results illustrated how fast and simple of making patterns by the LT-Tieup module. In addition, the LT-Weave module is another useful tool for pattern generation and modification. By using a combination of its four elements makes a flexible generation and modification, changing value only in one element affects a whole pattern that becomes a new pattern. In the experiment showed three examples of modification that were very simple, but they were very useful approaches.

5.2 Experiment and Result on Weaving

The aim of weaving experiment is to test our digital drafts with the electronic TC2 loom. The LT-Tieup module is a tool to generate both pattern-drafts and weave-drafts; the drafts are generated in both WIF file and image file formats by using LT-Tieup module. The experiment on weaving was separated into two phases, it conducted in weaving Laboratory of the faculty of textile design and clothing technology at Neiherrein University, Germany. In the first phase we had prepared only pattern-drafts with single weft-index, because it was the first time to work with the TC2 loom, we could weave only few patterns and we had got some feedbacks which leaded to the second phase of the experiment. The drafts for the second phase were weave-drafts that generated from three sets of pattern-drafts. The first set was pattern-draft with single weft-index; the second set was pattern-drafts with two weft-indices and the last set was pattern-drafts with three weft-indices. Weave results from the second phase were satisfied to our target. The details of the weaving experiment in each phase and their results will be explained as below.

5.2.1 First Phase of Weaving with the TC2 Loom

The first phase of weaving experiment was a first time to work with TC2 loom; it took hours to understand how the loom works. The TC2 loom for the experiment contained 660 warp threads; we had to generate digital drafts that were 660 pixels in width for image file or 660 warp threads for WIF file. The digital drafts for the experiment were pattern-drafts with one weft-index and then we used only one weft thread for weaving. In order to follow traditional Lao style, we used narrow Frieze patterns as a border patterns and used large Frieze patterns as main patterns. Totally there were 3 narrow Frieze patterns and two large Frieze patterns used in this weaving experiment. The patterns were decorated in groups to form style of Lao textile while plain weave was used to create spaces between patterns on the woven fabric. The weave is separated into two sections as illustrated below:

Weaving first section:

- Group 1: border patterns consist of *swan* and *diamond* patterns.
- Group 2: main pattern is a pattern of *diamond of Naga head.*
- Group 3: border patterns consist of *swan* and *diamond* patterns.

To weave first section of the fabric, we used three patterns and divided into three groups, the first and last groups are a combination of *swan* patterns and a *diamond* pattern to form a border pattern is shown in figure 5. 44. The second group was formed a main pattern; it was a pattern of *diamond of Naga head* is shown in figure 5.45. Actually, this main pattern was modified version of the pattern in figure 5.12 by expanding its width to 660 pixels and repeatedly displays the pattern without scaling. To visualize appearance of the digital drafts, we illustrated the drafts by binary image where yellow was foreground color and red was background color.

Figure 5.44
A digital border pattern formed by *swan* and *diamond* patterns

We use plain weave to create a space between the border patterns and the main pattern. Weaving result on the TC2 loom is illustrated in figure 5.46. We see that shapes of woven motifs are tiny; because we follow standard representation which is one pixel represented one true value of the binary data. This is our first observation from the experiment. In general the woven pattern looks fine, but if we closely look there were improper warp floating in some area of the woven pattern. This is a second observation we get from the first weave result.

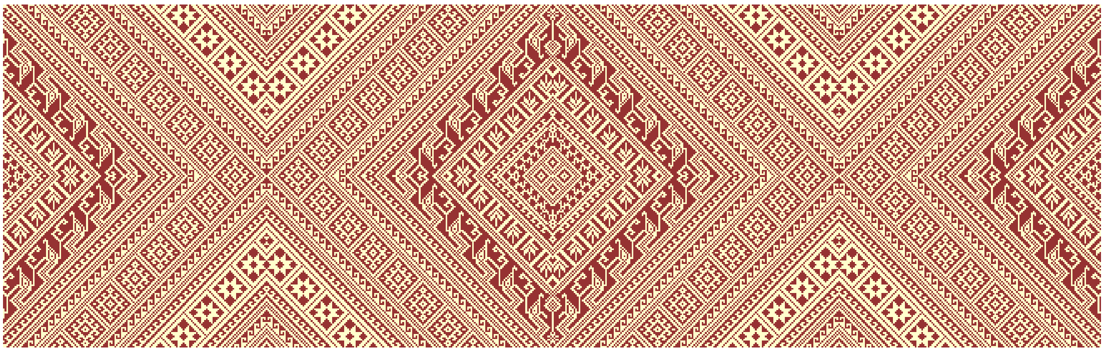


Figure 5.45
A digital pattern of *diamond of Naga head* (size: 660 x 201)

Figure 5.46
Weaving result of the first section on the TC2 loom

Weaving second section:

- Group 1: border patterns consist of *swan* and *small mating Naga* patterns.
- Group 2: main pattern is a pattern of *Siho.*
- Group 3: border patterns consist of *swan* and *small mating Naga* patterns.

To weave second section of the fabric, we use three patterns and divide into three groups as well; the first and last groups are a combination of *swan* patterns and a *small mating Naga* pattern and to form border patterns. The second group is formed a main pattern; it is a pattern of *Siho*. These patterns are continually woven without separating by plain weave. To compare weave result to its digital draft, we illustrate the draft in figure 5.47 and its weave result illustrate in figure 5.48. If we look at the result, shapes of woven motifs are tiny the same as the motifs of the result in previous section, but the fabric has improper structure due to the fabric contained very long warp floating. Actually, there is nothing wrong on the digital draft and the loom does nothing wrong as well. The problem is that we define the improper draft to the loom. If we look at the digital draft again and interpret it in weaving terms, yellow represents weft floating and red represents warp floating. Therefore, if we have long vertical space on the red area of the digital draft that means we will get long warp floating on the woven fabric. The results bring us to some observations on the weaving problems and finally we find solutions to solve the problems. The main keys for the solutions are:

- It is necessary to add plain weave in each line of a pattern in order to avoid the problem of long warp floating or long binding distances between wefts and warps.
- It is necessary to use at least two sets of weft thread, one weft is for plain weave and another weft is for pattern-weave.
- To generate a weave-draft for colorful pattern (using multiple weft-indices), it is necessary to separate a pattern into many layers and allocate each layer in different line before adding plain weave.

Figure 5.47
A digital weave-draft for weaving second section of the fabric, size (660 x 473)

Figure 5.48
Weaving Result of the second patterns' group on the TC2 loom

The results from the first experiment help us to understand why Lao weavers use compound weave technique or use plain weave to tie between lines of pattern-weave. They are clues for us to develop and to improve weave-draft algorithms in chapter 3. Definitely, we need more experiment on weaving to test the improvement of our algorithms, this lead us to have second phase of the weaving experiment that is going to explain in detail in the following section.

5.2.2 Second Phase of Weaving with the TC2 Loom

Because a structure of digital draft depends on weave type and number of weft-index defined in the draft, the second phase of the experiment we prepare weave-drafts of compound-weave with different number of weft-index, such as: weave-draft with one weft-index, weave-draft with two weft-indices and weave-draft with three weft-indices. The digital weave-drafts are generated based on 5 samples' patterns that prepare to weave with the TC2 loom. Details of the drafts and weave results will be explained as follows.

Weave sample1: weave-draft with one weft-index

Motif name: *mating Naga*
Source: Phaeng Mai gallery, Vientiane capital

We start the experiment from a simple draft which is a draft of compound-weave that contains only one weft-index and it is a weave-draft of *mating Naga* pattern. In order to visualize structure of the digital pattern and weave-draft, we illustrate a motif of *mating Naga* before adding plain weave in figure 5.49; it is a pattern-draft with one weft-index. A motif of *mating Naga* after adding plain weave is shown in figure 5.50; it becomes a weave-draft of compound-weave structure. A full weave-draft of *mating Naga* pattern with size 660 x 87 pixels is illustrated in figure 5.51. The draft is presented by binary image where the yellow indicates weft, and the red indicates warp.

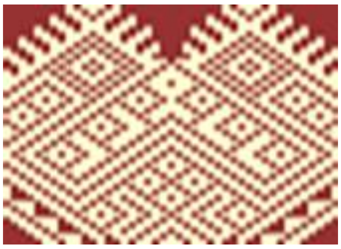


Figure 5.49
A motif of *mating Naga* before adding plain weave

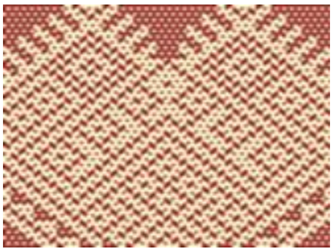


Figure 5.50
A motif of *mating Naga* after adding plain weave

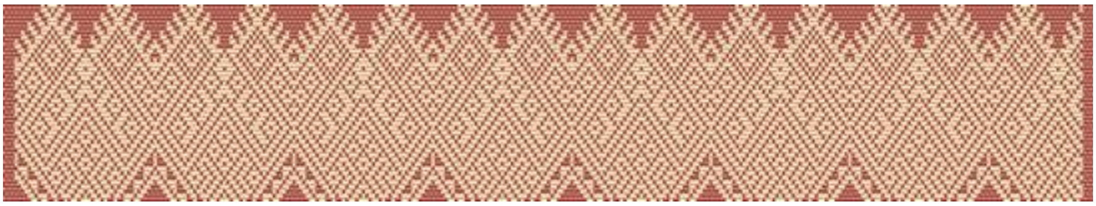


Figure 5.51
A digital weave-draft of *mating Naga*'s pattern (Size: 660 x 87)

We use white weft to weave the pattern and dark red weft to weave plain weave, a weaving result illustrated in figure 5.52. If we compare the result to the draft, we see that the result exactly looks the same as defined on the draft. Therefore, the loom follows a given draft and reads the draft row by row. The most important element to weave on electronic loom is a suitable digital draft. The result produces a fabric with fine structure, a woven pattern and its background are woven smoothly, there is no long warp floating found on this result.

Figure 5.52
Weaving result of the *mating Naga*'s pattern

Weave sample 2: weave-draft with two weft-indices

Pattern1: *swan* pattern
Source: Sam Neua skirt's hem, Hauphan province.
Pattern2: *diamond* pattern
Source: Lao Textile Museum, Vientiane capital.

To test a weave-draft of compound-weave with two weft-indices, we use border patterns from the first phase's experiment in figure 5.44. They are digital patterns of *diamond* and *swan*. We assign two weft-indices to the *diamond* pattern and assign one weft-index to the *swan* pattern. A digital weave-draft for the *swan* pattern with size 660 x 47 pixels is illustrated in figure 5.53, it is a binary image where the yellow indicates weft, and the red indicates warp.

Figure 5.53
A digital weave-draft of the *swan* pattern (Size: 660 x 47)

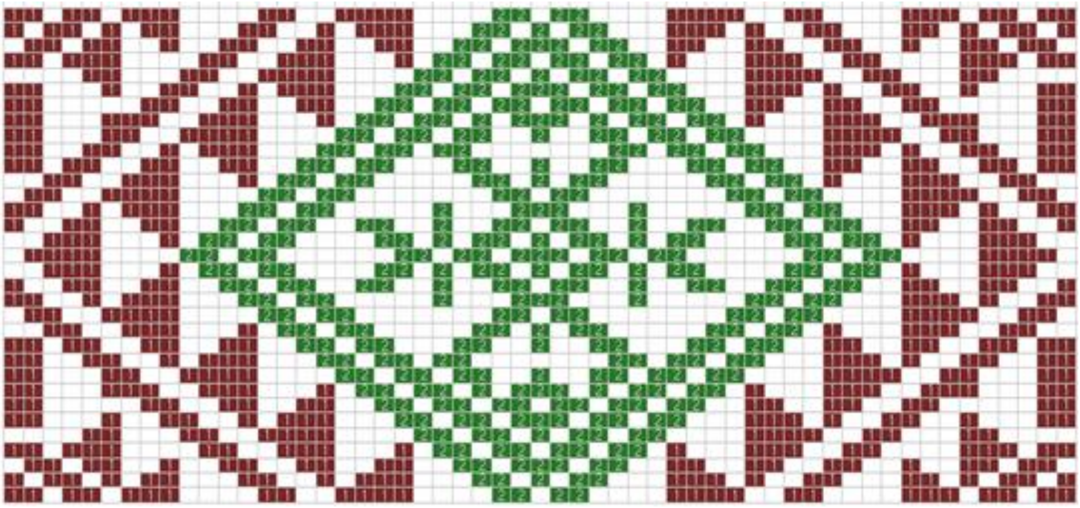


Figure 5.54
One-repeat *diamond* pattern with two weft-indexes, before adding plain weave

Figure 5.54 shows one-repeat pattern-draft (a motif) of *diamond* that generated by the LT-Tieup module. The red indicates weft-index 1 and the green indicates weft-index 2. The LT-Tieup module set default value of weft-index to one, but the module provides list of indices to define multiple indices to the design. Weft-index and color-index in the LT-Tieup module are different; this property allows us to define multiple colors to the same weft-index. Actually, colors on the pattern-draft help us to design desired ornament on a fabric; weft-index is used to generate weave-draft of compound-weave. The weave-draft is generated by separating each weft-index to different line then adding line of plain weave before repeat the process to the next line of the pattern-draft. The LT-Tieup module already implemented this ability; we only need to assign weft-indices to the design. The pattern-draft of our sample 2 contains two colors and two weft-indices; its corresponding weave simulation is shown in figure 5.55. The simulation illustrates a one-repeat weave-draft of the *diamond* pattern. The red indicates weft-index 1, the green indicates weft-index 2 and the gray indicates weft of plain weave. Due to a motif of the pattern is symmetric, in the first half of the motif a line of gray is inserted after every line of green (weft-index 2), but in the second half of the motif a line of gray is inserted after every line of red (weft-index 1), excluding the last red line.

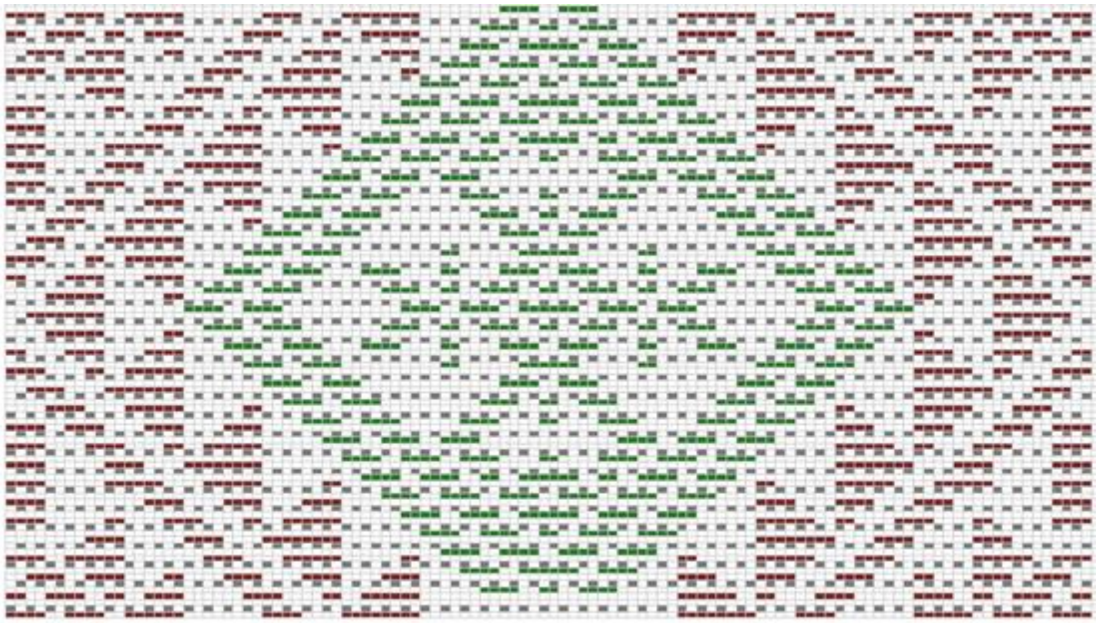


Figure 5.55
Weave simulation of one-repeat weave-draft of the *diamond* pattern with two weft-indices, after adding plain weave

From weaving result is shown in figure 5.56, we see that a woven *diamond* pattern is a colorful pattern; it is decorated with seven weft colors. Because the TC2 loom is semi-automatic electronic loom which is hand operated machine, so we are able to use set of weft threads more than number of weft-index that defined in the weave-draft. The weft-index on the draft is only used to determine groups of lifted warps for weaving. Because we consider on traditional Lao style, we still use hand-pick decoration in weaving. Once the warps lifted we are freely to decorate on the fabric.

Figure 5.56
Weaving result of the *swan* and *diamond* patterns

In chapter 2 introduced numerous styles of traditional Lao motifs, especially the mythical motifs which become a uniqueness of Lao textiles. Therefore, we select two popular mythical motifs for testing. The first motif is a big *mating Naga*; the second motif is a big *Siho*. They are popular and meaningful to Buddhist and shamanic weavers. We generate their weave-drafts by using two weft-indices that will be explained as below.

Weave sample 3: weave-draft with two weft-indices

Motif: mythical greater named *mating Naga*
Source: Lao Textile Museum, Vientiane capital.

The motif of sample 3 is a big *mating Naga*, original found in Lao textile museum in Vientiane capital of Laos. Figure 5.57 illustrates a digital pattern-draft of the motif, the red indicates weft-index 1 and the green indicates weft-index 2. We define two weft-indices for this motif because we need to decorate the red area and the green area in different weave steps. A separation helps us to speed up weaving and it makes weaving more comfortable. A digital weave-draft of the motif is shown in figure 5.58, the draft is binary image where the yellow indicates weft and red indicates warp. Once weaving on the TC2 loom, we used five weft threads in different colors to emphasize the motif and to produce colorful motif. The weaving result is illustrated in figure 5.59.

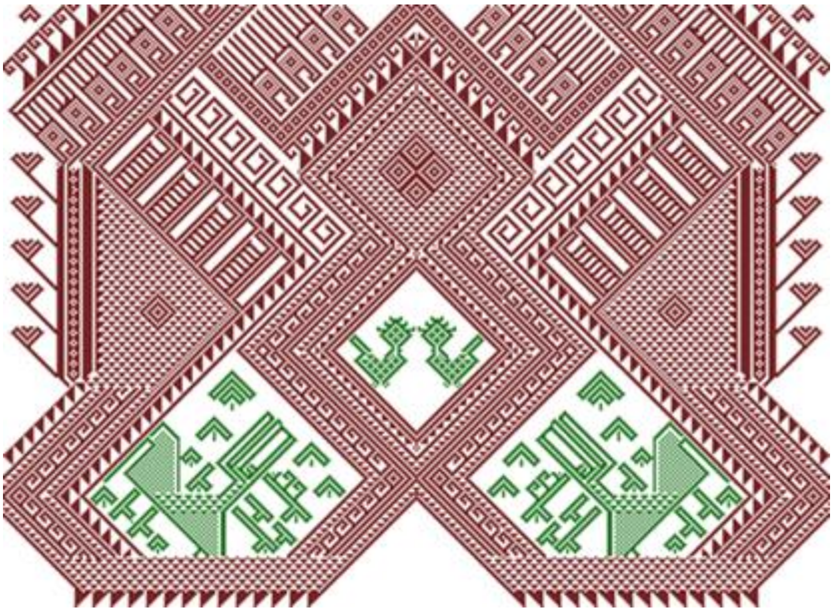


Figure 5.57
A *mating Naga* motif with two assigned weft-indices (Size: 323 x 236)

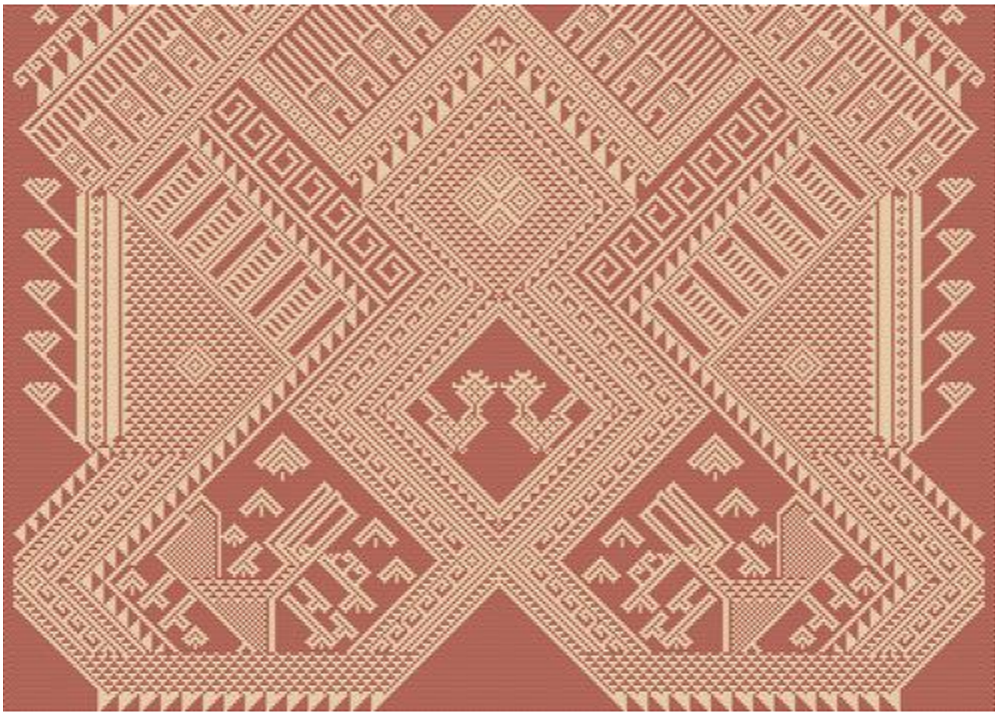


Figure 5.58
A digital weave-draft of the *mating Naga* motif (Size: 660 x 471)

Figure 5.59
Weaving result of the weave-draft of *mating Naga*'s motif

Weave sample 4: weave-draft with two weft-indices

Motif: mythical greater named *Siho*

Source: modified an original motif from Lao Textile Museum, Vientiane capital.

It is similar to the sample 3, the motif of sample 4 is a big mythical *Siho*; we modified an original motif found in Lao textile museum in Vientiane capital of Laos. Figure 5.60 illustrates a pattern-draft of the motif, the red indicates weft-index 1 and the green indicates weft-index 2. We see that the design is very complicated, if we need to weave colorful motif, we should define multiple weft-index in order to separate decoration into sections that is why we defined two weft-indices to the motif. A digital weave-draft of the motif is shown in figure 5.61, the draft is binary image where the yellow indicates weft and red indicates warp. During weave we used many weft threads in different colors to produce a colorful woven motif. The weaving result is illustrated in figure 5.62.

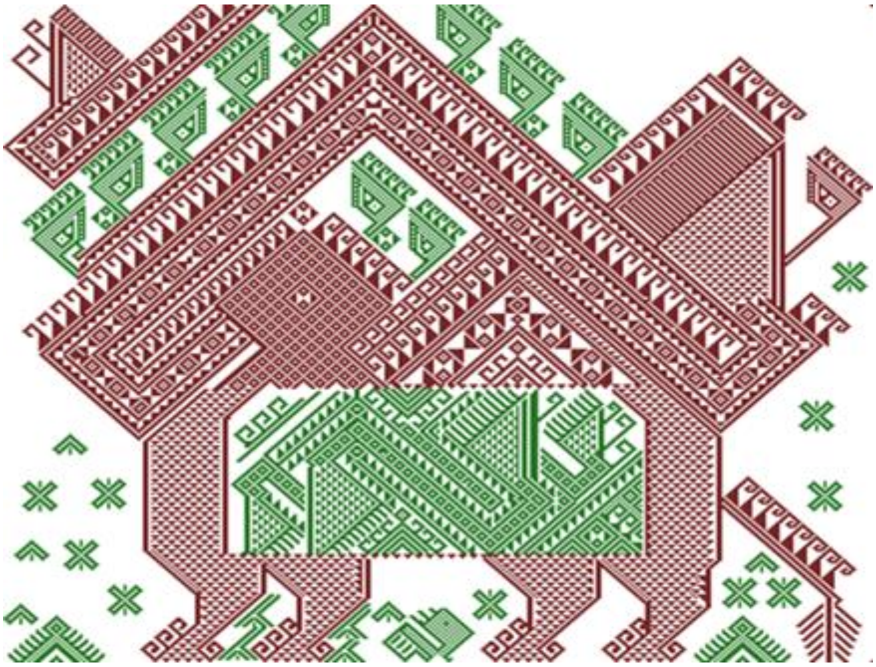


Figure 5.60
A *Siho* motif with two assigned weft-indices

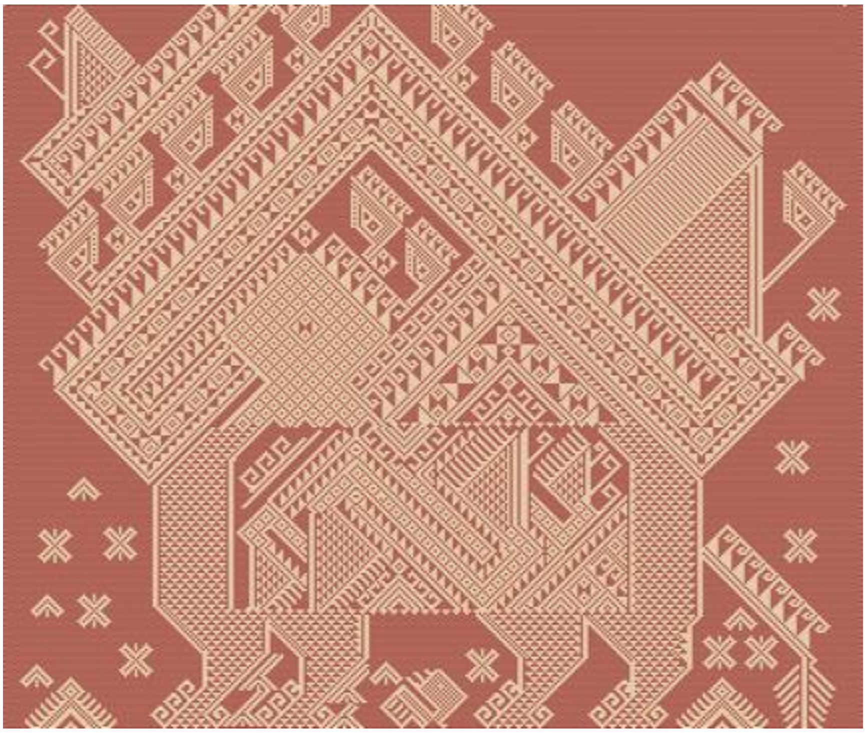


Figure 5.61
A digital weave-draft of the *Siho* motif (Size: 660 x 557)

Figure 5.62
Weaving result of the weave-draft of *Siho* motif

The weaving results from the sample 2 to sample 4 shows a variety of possibilities to decorate colorful motifs and patterns on a fabric. The weave-drafts are generated by using only two weft-indices, but we are able to produce a variety of colorful styles. The decoration is still up to imagination of designers. In the next section we will experiment on a weave-draft with three weft-indices in order to explore complexity of the digital draft and flexibility in weaving.

Weave sample 5: weave-draft with three weft-indices

Pattern: *diamond of Naga head*
Source: Sam Neua's shawl, Hauphan province.

The last sample of the experiment is a symmetric motif of *diamond of Naga head*, its original found on shawl in Sam Neua city of Hauphan province. It is another example of complicated motifs. Its pattern-draft and weave-draft are generated by the LT-Tieup module. The one-repeat pattern-draft with size 284 x 137 pixels is presented in figure 5.63; the red indicates weft-index 1, the green indicates weft-index 2 and blue indicates weft-index 3. Its corresponding weave-draft, weave simulation and weaving result are illustrated from figure 5.64 to figure 5.66 respectively.

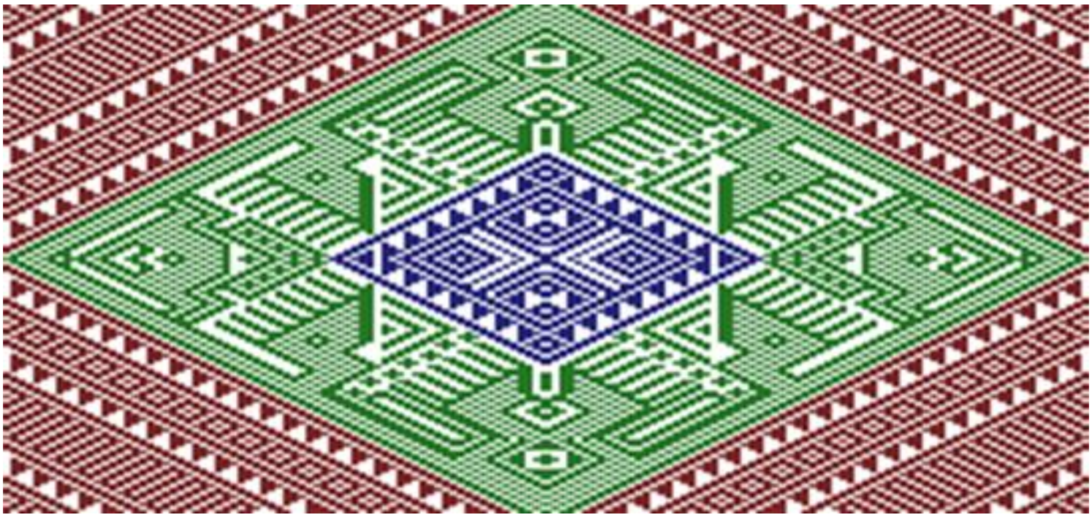


Figure 5.63
A motif of *diamond's Naga head* with three assigned weft-indices (Size: 284 x 137)

Due to the motif is symmetric, the simulation shows that in the first half of the motif, a line of gray is inserted after every line of blue (weft-index 3). But in the second half of the motif, a line of gray is inserted after every line of red (weft-index 1), excluding the last red line. Figure 5.65 illustrates a digital weave-draft generated in binary image, the yellow indicates weft and the red indicates warp. Figure 5.66 shows weaving result, it is decorated with three wefts in different colors to emphasize diamond shapes on a fabric.

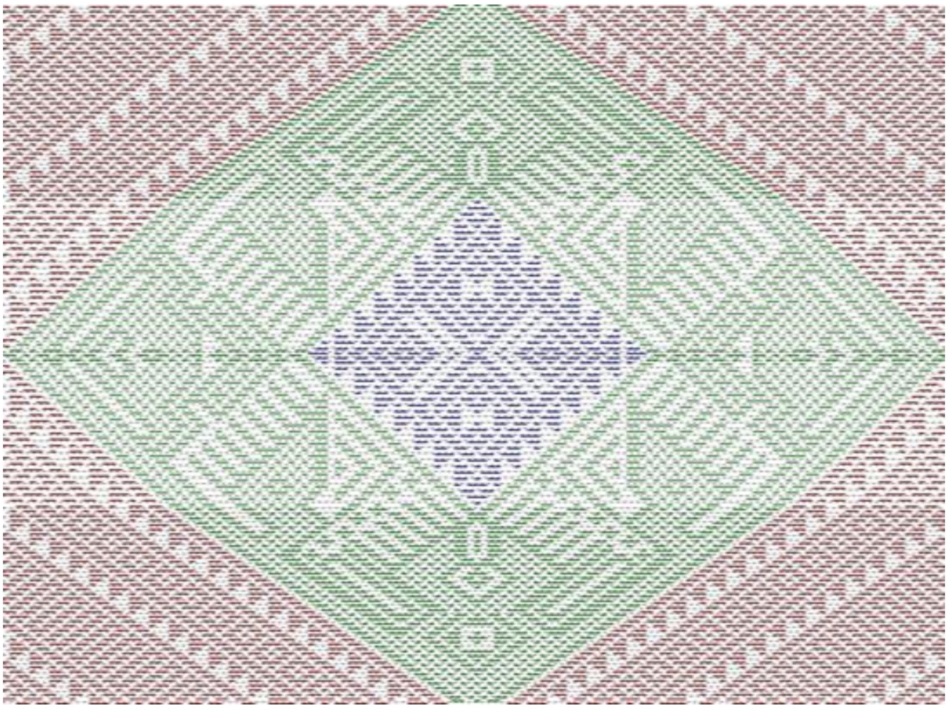


Figure 5.64
Weave simulation of *diamond's Naga head* motif with three assigned weft-indices, after adding plain weave (Size: 284 x 458)

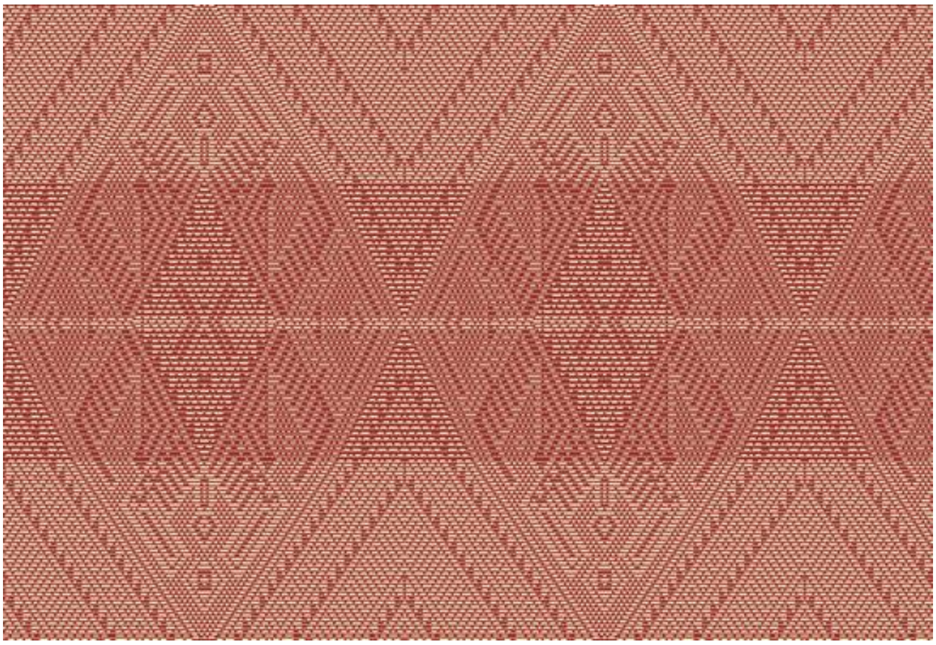


Figure 5.65
A digital weave-draft of the pattern of *diamond's Naga head*
(size: 660 x 458)

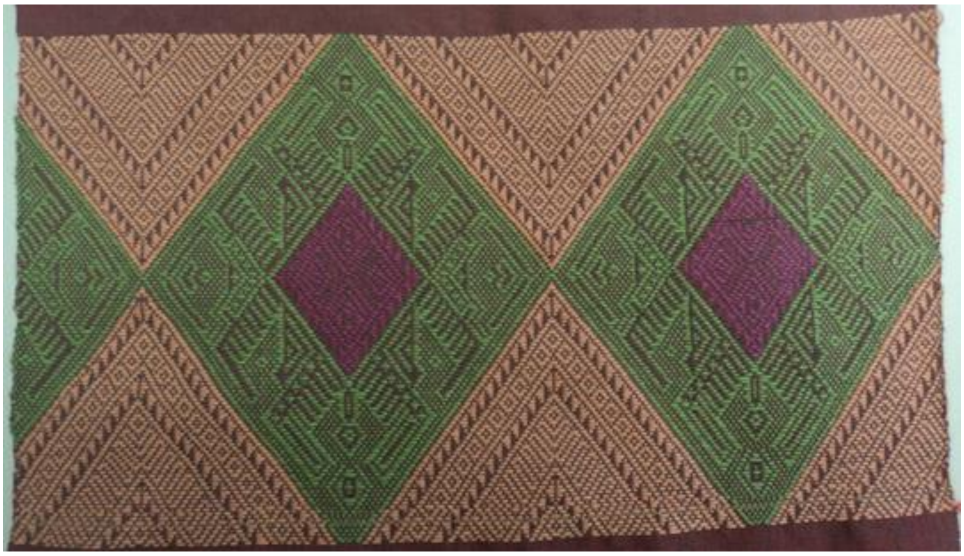


Figure 5.66
Weaving result of the weave-draft of the pattern of *diamond's Naga head*

5.2.3 Summary on Weaving Experiment

The weaving experiment gives us two types of results. The first type is results of digital weave-drafts that are generated by the LT-Tieup module. The second type is results of woven fabrics that are woven by implementing style of traditional Lao textile. Because digital weave-drafts are necessary elements for weaving with electronic loom, a variety of digital weave-drafts used in the experiment shows ability of the LT-Tieup module. The results depict suitability and comfortability for using the LT-Tieup module to generate digital weave-drafts. The module provides flexibility in design and provides simple steps to generate drafts in many structures. The samples for experiment are predominant motifs which are uniqueness of Lao textiles. The digital weave-drafts are various from weave-draft with one weft-index to weave-draft with three weft-indices.

The weaving results show compatibility between our digital weave-drafts and the electronic TC2 loom. The results show a variety of colorful motifs and patterns on a fabric. Because the TC2 loom is a hand operated loom, it provides various possibilities to decorate fabric; this property satisfies the characteristics of Lao textiles. The experiment focuses on weaving style of traditional Lao textile which consists of pattern-weave and ground-weave (plain weave). Therefore, a hand-pick decoration is used to weave a complicated pattern. The decoration is up to imagination of the designers even weaves the weave-drafts with few weft-indices, but we are able to produce many colorful styles. The produced fabrics look the same like fabrics that are woven on Lao floor-loom. Therefore, the results express a connection between traditional style of Lao textiles and modern weave technology. They fulfill the gap between traditional weave technique of Lao weavers and modern weave technique; they satisfy the goal of our research.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

The overall goal of this research is to preserve and to make a contribution to traditional Lao textiles which are a cultural heritage of Laos on clothes. The research has found that the connection between hand-weaving and electronic weaving is a modern solution to preserve this culture and the key is a digital weave-draft. Therefore, the research proposed digitizing methods and algorithms for creating digital data models of traditional motifs and patterns, and then implementing them in three separated Lao Textile (LT) design modules with specific design purposes, such as: the LT-Tieup module, mainly use for motif and pattern constructions, the LT-Weave module with a focus on motif and pattern modifications and finally the LT-Design module, which is used for textile design and textile visualization. The digital file formats for this research are WIF and image files, which are standard formats, understandable and useable for both hand-weavers and electronic looms. The research is a disciplinary research between scientific computing and digital textile design and weaving, so the research conclusively consists of three main phases. The first phase is to collect and analyse data; the second phase is to investigate and to implement scientific methodologies for digitizing and archiving; the last phase is to experiment the methodologies and the developed tools. A summary on each phase illustrates as follows.

6.1.1 General Findings on Lao Textiles

In terms of cultural heritage, traditional Lao textiles play an important role in the Lao society and the present religions, the design and arrangement of patterns on the textiles represent the religious beliefs of the people. We found that traditional Lao textile is always decorated with various pattern's styles and various pattern's sizes. The patterns are random or sequential arrangement. In addition, traditional Lao textile is a wealth of religious motifs which display hidden traditional meaning. We discovered that traditional Lao motif generally contains hierarchical structure. The motif is a composite figure that consists of many layers; each layer is constructed by either lined motif or single motif. In this research, the motifs and patterns are collected from the north to the south of Laos and we categorized the motifs into five categories based on their appearances and characteristics. The first category is a group of *Naga* motifs which significantly symbolize and characterize Lao society and culture. Figures of *Naga* on textiles are inspired from shamanistic and Buddhist beliefs. The *Naga* figures on clothes are interpreted as wearer's protectors from dangers. The second category is a group of *Siho* motifs. *Siho* is a mythical creature from epic narratives and the motif of *Siho* mainly decorates shamanist textiles. The figure of *Siho* is considered to be a spiritual animal of that a shaman can use to go to the spirit world and return from it. The third category is a group of *giant* motifs which represents a mythical creature from epic narratives and Buddhist myths. The figures on textiles are also considered as the wearer's protector. The fourth category is a group of *bird* motifs which consists of motifs of general poultry and motifs of mythical birds. Eventually, the last category is a group of plants, animals and other symbols.

6.1.2 Methodologies and Implementations

In terms of scientific computing, this research investigated scientific methods and algorithms for digitizing motifs, patterns and textiles. We developed three Lao Textile (LT) modules for design and digitizing, they are the modules LT-Tieup, LT-Weave and LT-design. The mathematical representations of digital textiles and its components are based on binary matrix. Regarding characteristics of traditional Lao motifs, we separated digitizing motifs into two types: lined and single motifs. Geometric structures of symmetries are theoretical resources for motifs design and digitizing, especially geometric structures of the cyclic and dihedral groups. The geometric structures of the symmetry groups were implemented in the LT-Tieup module for motif design. For patterns design and digitizing, we presented 7 algorithms to generate 7 styles of Frieze patterns and 16 algorithms to generate 16 different styles of wallpaper patterns. These algorithms were implemented in the LT-Tieup module to facilitate pattern design. We additional presented mathematical formula for motifs and patterns digitizing by simulating four components of floor-loom, and then we implemented the formula into the LT-Weave module.

For digitizing weave-drafts, we defined weft-indices to generate the drafts. The digital weave-drafts are generated based on the weft-face patterning technique in Lao called "Tam Chok". Its woven fabric consists of at least two sets of wefts, one set is the weft thread of ground-weave or plain-weave and another set is the weft thread of weft-face patterning. Therefore, this research separated digital drafts into two types, a pattern-draft and a weave-draft. The digital pattern-draft is a draft for both hand-weavers and electronic looms. It is a draft for pattern-weave that contains only pattern structure; hand-weavers can directly follow the draft for creating a manual weave-draft on a floor-loom. The digital weave-draft is only a draft for electronic looms, because the draft is applied compound-weave, which is a combination of pattern-weave and ground-weave. Regarding colorful fabric, we presented algorithms for generating pattern-drafts and weave-drafts by considering weft-indices, which are keys to determine a final result of the digital drafts. These algorithms were also implemented in the LT-Tieup module. For textile design and digitizing, we developed the LT-Design module. Since motifs and patterns are textile's elements, the LT-Design module was embedded features of the modules LT-Tieup and LT-Weave to support particular modification, such as motif or pattern modifications. In general, these three design modules are tools to produce digital data models for archiving.

To archive digital data models, we developed the online repository for online digital archiving. The aim of the development is not only to store digital files of traditional Lao textiles, but also to use it as a tool for communication among weavers, researchers and cultural heritage experts. Based on required information and characteristics of traditional Lao textiles, we used a web content management system named Omeka as a tool for building a website. Omeka is widely used in many fields for online digital archiving, for example in libraries and in museums. The structure and page flow diagram of the website are showed in chapter 4. Digital data models of motifs, patterns and textiles are stored and organized in a separate page which is linked to the collection page and provided there as a category on. The visitor and users of the website are able to find all digital data models on the collection page; especially users are able to download and upload any digital data model from/to the website.

6.1.3 Digitizing and Weaving

Due to the methodologies and algorithms were implemented into the developed LT design modules. We evaluated them by experiment on digitizing and weaving, we used the LT design modules as tools. Generating digital motifs and patterns proceed in digitizing experiment while making digital weave-drafts was included in weaving experiment.

For generating digital motifs, we experimented on both lined and single motifs. The experiment showed that making a lined motif is simple, the process requires small unique segment as input, but we can get a line as long as we need. From few lined motifs, we are able to random generate various combination of them for making a big hierarchical motifs. To generate single motifs, we separated the experiment into two approaches. The first approach, we applied symmetry groups of the cyclic and dihedral groups in the LT-Tieup module. We found that the module worked well, a key for generating is a unique segment of each symmetry group. If we give a proper segment then we will get a correct motif. In the second approach, we experimented by using image processing techniques. The outputs from this approach would be imported to the LT-Tieup module for further modification. We investigated three filter sequences to explore a better result. The first sequence used mean filter, the second sequence used median filter and the last sequence used adaptive filter for noise removal and edge adjustment. The experiment's result showed that generally the mean filter give better result than the median and adaptive filters. However, in terms of digital pattern-draft, the results were still far from traditional style of Lao motifs. Changing to Lao style they must be a lot modified. If we compare the second approach to the first approach we found that using the LT-Tieup module is accurate and the module directly supports design of Lao traditional style.

For generating digital patterns, we experimented on both Frieze and wallpaper patterns. The experiment mainly applied symmetry groups of the Frieze and wallpaper groups that implemented in the LT-Tieup module. Generating patterns is similar process to generate motifs of the cyclic and dihedral groups. We found that the motifs of the cyclic and dihedral groups are elements of the Frieze and wallpaper patterns while the Frieze patterns are elements of the wallpaper patterns. From a given unique segment, we are able to create more than one pattern. The results of experiment illustrated how simple of using the LT-Tieup module to produce absolute structure and create Lao traditional style for both motifs and patterns digitizing.

In weaving section, we evaluated and got two types of results. The first type was results of digital weave-drafts that were generated by the LT-Tieup module. The second type was results of woven fabrics that were woven by implementing style of traditional Lao textile. The hand operated TC2 loom was a selected tool for weaving. We tested the weave with various digital weave-drafts, ranging from weave-drafts with one weft-index to weave-drafts with three weft-indices. The results depicted compatibility of our digital weave-drafts to the TC2 loom. The research focused on traditional style of Lao textile, a hand-pick decoration was still used to weave a complicated pattern. The decoration was up to imagination of the designers. As a result, we got a variety of colorful motifs and patterns on a fabric, the results expressed a connection between traditional style of Lao textiles and modern weave technology. The weaving's results proved that our digitizing methods fulfill the gap between traditional weave technique of Lao weavers and modern weave technique. In addition, we found that the LT-Tieup module is the most useful and flexible tool, while the LT-Weave module is a suitable tool for pattern modification and the LT-Design module is particular tool for textile design and modification.

6.2 Future Work

In cultural terms, we have a list of some possibilities to improve research in the future. The first possibility is to investigate weaving techniques applied on backstrap looms, because the backstrap loom is a main tool used among small ethnic groups in southern Laos. Therefore, the design software tools need to improve to implement weave structures of the backstrap loom. The software tools will be central to exchange and to contribute to weaving culture among local weavers in every ethnic group of Laos. The study on modern weave structures and their implementation to traditional hand-weaving is another possibility for future work. The idea is to keep appearance of traditional motifs, but woven fabric could be applied to various structures. The result would produce interesting textiles with good quality and still a traditional Lao style. Regarding cultural preservation, we have a future perspective to exchange within the weaving culture of neighbouring countries in Southeast Asia, such as Thailand, Cambodia and Vietnam. We have talked to people at the Goethe-Institute in Bangkok, Thailand in order to process this perspective in future; we aim to contact the UNESCO as well to figure out an improvement for future research in order to register traditional Lao motifs as intangible cultural heritage.

In scientific terms, we have a future perspective to digitize weaving patterns from punch cards of historical Jacquard looms and vice versa to generate weaving codes on punch cards for historical Jacquard looms. Nowadays, many textile museums in Europe have many types of ancient Jacquard looms, those looms still work but their original punch cards are very old and they are very easily damaged. It is difficult to use them for weaving. Therefore, a requirement for generating a copy of original punch cards has arisen. The copy version of punch cards is for testing and to show how the historical Jacquard looms work. This possibility is one of the challenges in research, because there are many types of punch card Jacquard looms that need different sizes and different coding mechanisms. An investigation aiming to find common components between coding mechanisms is the key to define a formula and an algorithm for generating weaving codes on various sizes of punch cards.

The second possibility in scientific terms is more investigation on image processing techniques for extracting digital motifs from traditional Lao images. In chapter 5, we introduced basic image processing techniques for digitizing traditional Lao motifs, a method which was used as an optional technique for getting initial digital motifs before importing to the LT-Tieup module. The experiment's result on image processing techniques in this research has shown that there is more investigation needed, in order to get precise shapes complying with the original design or in order to follow weave designs as traditional Lao style. Due to characteristics of traditional design for Lao motifs, research on extracting traditional Lao motifs from images will be a challenging research project.

The last possibility to take this research further in future work is to retrieve digital data models from online repositories, Using geometric shape descriptors is one possibility in future work. With an image retrieval system that stores new and old motif designs in digital form, the task of searching, storing and retrieving these motifs will be much easier and faster. Since the database is growing from time to time, automatic extraction of feature vectors and real-time indexing can be computed efficiently. Furthermore, since matching is done online, the simple Euclidean distance can be used to compute similarity measures of these descriptors.

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