Contents

Chapter 01: Introduction to Zombie Spiders  Page 07
Chapter 02: What do Zombie Spiders transform?  Page 15
Chapter 03: Why do they transform their net structures?  Page 21
Chapter 04: How do these transformations happen?  Page 29
Chapter 05: Transfer of identified Strategies to an Architectural Scale  Page 39
Chapter 06: What is the architectural interpretation?  Page 43
Chapter 07: Why are these transformation strategies interesting?  Page 47
Chapter 08: How can fibrous morphologies be transformed?  Page 51
Chapter 09: Appendix: Additional Material  Page 59
Chapter 10: References  Page 75
Transformation of Fibrous Structures

BIOLOGICAL RESEARCH

- CHAPTER 02
  - What do Zombie Spiders transform?

ARCHITECTURAL INTERPRETATION

- CHAPTER 06
  - What is the architectural interpretation?

- CHAPTER 03
  - Why do they transform their net-structure?

- CHAPTER 07
  - Why are these transformation strategies interesting?

- CHAPTER 04
  - How does this transformation happen?

- CHAPTER 08
  - How can fibrous morphologies be transformed?

Appendix

- REFERENCES
  - CHAPTER 09
    - pg. 39
  - CHAPTER 10
    - pg. 75
Host spider manipulation by parasitic wasps is a true example of a fascinating phenomenon: mind control in nature. This introduction will explain such host manipulation, its origin and its function.

This complex process happens through host manipulation (fig. 1.1) where a parasitic agent chemically induces its host organism to generate alternative behavior. When a wasp successfully attacks a host spider at the hub of its orb-web, it temporarily paralyses it to lay an egg on the tip of the spider’s abdomen. After that, the spider regains normal activity and during the next 7-14 days it builds apparently normal orbs to capture prey, while the wasp’s egg hatches and the larva grows by sucking the spider’s hemolymph (fig. 1.2).

The parasitoid is able to turn the spider into an agent which modifies a normal orb-web structure (fig. 1.3A) into a specific and more persistent ‘cocoon web’ (fig. 1.3 C) (Eberhard, 2000). This structure will allow the wasp to pupate safely against the elements or enemies after the spider’s death. The importance of having such a strong and durable support for the wasp’s pupae demonstrates the vulnerability of the wasp’s pupae towards heavy rains.

Many parasites manipulate their host’s behaviour but most of them, particularly insect parasitoids, induce only simple changes, such as movement from one habitat to another, eating more or less, or sleeping. To this respect the Hymenopteran’s wasp manipulation of its spider host, Plesiometra Argyra, has been considered one of the most precise directed alterations of behaviour ever attributed to an insect parasitoid.

The behavioural change in the host spider can be understood in the web-building steps and its final cocoon web state. Furthermore, manipulated host mechanisms can be derived by comparing the functions between the unmanipulated (normal) webs and the manipulated end product (cocoon web).

According to a research paper by Takasuga et al. (2015), a specific ectoparasitoid (R. Nielsen) evokes resting web construction behaviour intrinsic to Cyclosa Argentea and the Ecdysteroid-related components could be responsible for the manipulation.
To clarify the origin and function of cocoon webs and to understand the reason for the spider to invest time and energy in building such nets, spider web-building behaviour, resting and cocoon web structures were investigated, also including the silk tensile properties of both structures. Scanning electron microscope images show that fibrous thread decorations on radii of resting webs (fig. 1.4 A) and cocoon webs (fig. 1.4 B) are very similar in structure. However, radii are laid down in greater numbers in the cocoon web than in the resting web. The breaking force (Mm) of radial and frame threads is notably higher in the cocoon web rather than in the other two web types while there is no difference between normal orb web and resting web in both radial or frame threads (fig. 1.5 A). By looking at each thread type strength and diameter (fig. 1.5 A,B), the Breaking Stress shows no relevant difference (fig. 1.5 C), pointing out that all threads consist of materials having same mechanical properties. The Young’s modulus of frame threads of orb and cocoon webs is highly different due to the cocoon radii being reinforced multiple times (fig. 1.5 E) and this also applies as comparing radial threads of orb/resting webs and cocoon webs. (fig. 1.5 D)

It has been understood that the sequence of behavioural manipulation is stereotypical in all parasitizes spiders. Manipulated spiders construct cocoon webs on the site of their original orb web. Behavioural manipulation begins with the spider retrieving the sticky spiral and then making repeated complex radial trips away from the hub and back whilst laying additional radii in both directions, without any laid threads being broken or reeled up. Shuttling on the frame threads for reinforcement occurs during the same trip, resulting in multiple attachment points to the substrate. At the latter phase of manipulation, the spider repeatedly flaps its fourth leg-pair to spray fibrous threads onto radii. Fibrous thread decorations are laid only on radii and never on the frame and all the spraying behaviour occur on the way back to the hub from the radial trips.

Though the spider decorates the radii on the radial trips away from the hub, it quickly reverses its steps and keeps decorating towards the hub. After every webbing bout, the spider always sits on the hub. When cocoon web construction is finished, all spiders stay stationary on the hub and seem to patiently wait for the wasp larva to start ingesting them. It takes the spider over ten hours on average from the withdrawal of the spiral web to the final resting of the spider at the centre of the hub web just before being killed. These cocoon webs are usually constructed in darkness, between sunset and sunrise, although it has been observed that other spiders construct it in the early morning or evening. Understanding the mechanism of host manipulation is a very complex task. Eberhard (2010b) theorizes that larval effects can be strictly related either on cumulative or dose-dependent processes rather than many different factors singularly responsible for influencing the manipulated spider’s behaviour.
This theory is supported by the fact that removing the parasitoid larva from the spider caused the spider to recover and get back to its normal web-building behaviour in the inverse steps previously used to build the cocoon webs during its manipulated behaviour.

The Polysphinctine larvae evokes a specific web construction that is exclusively limited to an exact life-history stage. The wasp larvae produce a signal molecule responsible for the beginning of the mind-controlled spider behaviour (Korenko and Pekár, 2011).

Another important feature of the R. Nielsen larvae which seems to be less frequent in the other two web constructions, resides in dragging the host spider to weave threads repeatedly, keeping the other building-web steps (such as retrieving sticky spiral webs and fibrous thread decorations construction) as normal.

The Reclinervellus Nielsen larvae is able to control the frequency of a particular independent resting web construction subdivision. Similarly, it is possible to have a case of another polysphinctine, the Hymenoepimecis argyraphaga larvae, which is able to force the spider to repeat some of the early steps of the orb-web construction, while neglecting the others. (Eberhards, 2000, 2001).

The R. Nielsen larvae injects chemical components which correspond to the molting hormone into host spiders, triggering the building process of the cocoon web. As the resting web construction is governed by ecdysteroids, the theory of the signal molecule triggering the process of the mind-controlled cocoon web syntax seems to be valid.

Similarly, the dose-dependent hypothesis, appears to be an equally valid theory; as the ecdysteroidal concentration gradient causes several behavioural responses in juvenile insects in a dose-dependent manner. Resting web construction consisting of several sequential building behaviours is likely to result from the same effect. The manipulative substance may react with the spider’s endocrine system in a similar way, supporting the dose-dependent hypothesis.
Chapter 02: WHAT?

WHAT DO ZOMBIE SPIDERS TRANSFORM?
After getting paralysed, zombie spiders begin to transform its normal webs into a “cocoon web” which is very different in terms of geometry, silk properties and function. These two types of webs serve for different ends of their masters, the spider or the lava. All the transformation strategies are aiming towards the goal of building a stronger, more durable support for the larva, and losing its original properties of a sticky orb web. We will discuss these changes in the terms of geometry, function and silk properties among several species.

Manipulated Web Construction Behaviour

In the case of orb web spider Plesiometa argyra, after paralyzation by the larva of the parasitoid wasp, Hymenoepimecis argyphaga Gauld, the spider repeats its early steps of a normal web construction routine, so that the first few threads of the orb web is reinforced multiple times, while the temporary and sticky spirals are missing, with the central portion of the orb web not being removed. (Eberhard 2000a)

The changes of two types of webs indicate that the cocoon web is elaborately designed for the hanging of the cocoon in high air, where sticky fibers with no structural benefits are no more produced by the manipulated spider.

Some cocoon webs have circular lines similar to those at the hubs of normal orbs. Anyways in no case the central portion of the hub is empty, as in normal orbs. Some have one or more frame lines connecting the radial lines. These frames were typically much shorter and nearer the hub than were the frame lines of normal orbs.

Experimental removal of the larva before it kills the spider was done by Prof. Eberhard’s team to see how the zombie spider will continue its zombie-mode construction under still prevalent but reduced chemical effect.

More complex 3-D cocoon-type web were recorded in the lab in Figure 2-2(15). And if the larva is removed earlier(5 days), the web will end up with something between orb-like normal web and cocoon-type web as shown in Figure 2-2(16), indicating the zombie spider is somehow recovering.
Manipulated Web Reconstruction Behaviour

In the case of spider Cyclosa argenteoalba manipulated by the larva of the parasitoid wasp Reclinervellus nielseni, similar behaviour is studied by Prof. Keizo Takasuka from University of Kobe in Japan. Under normal circumstances, this species of spider spins two different types of web: a “normal orb web” that looks like a typical spider’s web with a spiral of sticky threads that is used for catching prey, and a “resting web” which lacks the sticky spiral that is spun just before the spider moults its old exoskeleton. After the larva hijacks the spider’s nervous system, the spider is forced to transform its orb web into a cocoon web, which is similar to its resting web. The altered cocoon web is stronger, therefore more durable and perfect for the cocoon to be hanged in the air for the pupation of the larva, as suggested by the biologists.

The function of the transformed web therefore is fundamentally changed. It’s not designed for catching preys any longer, so the sticky spirals are missing. The reduced web density of the layout will help protect the insects. The cocoon web is constructed with thicker silk so the web is more durable and robust. The load case of the webs is also changed from small dynamic impacts of preys to static concentrated load of the hanging cocoon.

The manipulated spider transforms the already built orb web into a voronoi-like cocoon web by lacing, gluing, adding, bundling, as well as relaxing fibers which will be further discussed in Chapter 4. The sticky spirals are all recycled as food for the larva later when the larva consumes the spider. That introduces also the idea of material efficiency in the prevalent Zombie Spider’s webs.
Chapter 03: WHY?

WHY DO ZOMBIE SPIDERS TRANSFORM THEIR NET STRUCTURES?
The transformation of the normal orb web to the cocoon web is aiming towards the safety of the hanging cocoon. We will discuss the reasons behind from the perspective of material, structure and web configuration.

Material Properties

The material properties of silk used in both webs are almost of same stiffness. But as being reinforced multiple times, the threads in cocoon webs are much more thicker than the silk in normal orb web, so that the cocoon web is more robust than the normal web. In the orb web failure is accepted and even planned, as the spider is constantly there to maintain and reconstruct the web when it’s destroyed by insects’ impact. In a cocoon web reconstruction is impossible.
Compactness and Structure Efficiency

The density of the web configuration is significantly changed according to studies on multiple species. The most recognizable difference in the web layout is the missing of the sticky spirals and the voronoi-type layout of the radii. Some of these cocoon webs have relatively simple 2-D layout while others are very complex 3-D structures of elaborate design. But the laying of fibers should be carefully done by the manipulated spider because the material efficiency matters a lot in the construction process - the threads the zombie spider digests but doesn’t lay out again mean extra food for the larva when it consumes the spider.
If we assume that two types of webs are under same prestress, by simulating their structure behaviour in ANSYS, we can study the efficiency of normal orb webs and voronoi-type cocoon webs.

- comparison of maximum displacement
  1. under self-weight: orb’s max displacement is 75% of the cocoon web.
  2. under concentrated load (hanging of a cocoon): orb’s max displacement is 110% of the cocoon web.

- comparison of utilization (mean force density along each thread in web structures)
  1. under self-weight: not much different
  2. under concentrated load: spirals in the orb web become sag. Only needed threads remained in the web.

The simulation is somehow just telling part of the story because difference in “initial stress” is not concerned (same pretension is applied on both), which will even reveal bigger potential of the cocoon web because the initial tension is bigger in the case of cocoon web which will lead to smaller displacement and higher utilization of material.

(The script of ANSYS analysis is attached in Appendix(FIGURE 9.1))
Chapter 04: HOW?

HOW DO THESE TRANSFORMATIONS HAPPEN?
The most interesting but complex story consists in the transformation process of these two web types. We had a close look at the research materials from articles, images and videos. Based on our understanding of these researches we’ve were able to do some abstractions, which will be discussed in this chapter.

Prof. Eberhard has studied the silk-laying behaviour of zombie spiders analysed as the graph shown above. He has also studied the transformation process more abstracted step by step on from normal orb web into cocoon web. (FIGURE 4_2)

In order to pinpoint every move of the spider, we closely looked at one video captured transformation sequence and abstracted the key aspects of the manipulated web transformation strategies. (FIGURE 4_2)

We also analysed the transformation process more abstracted step by step on from normal orb web into cocoon web. (FIGURE 4_3)
FIGURE 4.3: Transformation Abstraction. (Source: Jingcheng Chen, Dominga Garufi, Dongyuan Liu, Hans Jakob Wagner)
Based on our study on the principles and strategies from our role model, we put our hands on small scale models to better understand local configurations of the web structures. We chose two main strategies to look deep into, which are bundling and connecting of fiber threads — the most common and essential transformation process. (FIGURE 4.4S)

What these strategies have in common is that they are both incrementally tensioning the resisting web structure during the transformation process. This potentially leads to a higher material efficiency or structural behaviour as we discuss in Chapter 3.

(* Refer to appendix to see more models that were used for testing different transformation strategies (FIGURE 9.4).)
Chapter 05: TRANSFER
TRANSFER OF IDENTIFIED STRATEGIES TO AN ARCHITECTURAL SCALE
PREMISES OF TRANSFER

Considering the transfer from biological transformation strategies to architectural applications of such, it is essential to firstly discuss the variables and differences in-between, to understand the feasibility and methodology of this undertaking:

1. Due to the fact that spider silk is a very elastic material (Young’s Modulus 1-5 GPa) (Figure 5.1), whereas carbon fibres are more strong and stiff (Young’s Modulus 30-50 GPa) (Figure 5.2), considerations need to be taken on how to deal with different material properties and behaviours. Transformation strategies need to be altered accordingly.

(* Several material tests have been carried out to test carbon fiber properties and more specifically the joint behaviour. Refer to appendix to see more information (Figure 9.3))

2. An architectural structure, for instance a pavilion, has normally a diameter of approximately 6 meters, which is far more bigger than a typical spider web that has a diameter of normally not more than 20-40 centimetres. This indicates a huge difference regarding scale that does not only effect structural performance.

Taking these differences into consideration, the transfer from biological transformation strategies into architectural ones should concentrate on the methodology and transformation process, instead of just a superficial structural imitation which may probably not work when scaled up to architectural scales with different material usage.
Chapter 06: WHAT?

WHAT IS THE ARCHITECTURAL INTERPRETATION?
Inspired by our Zombie-Spider rolemodels, we investigated possibilities to change existing fibrous structures. The most stunning part of Zombie Spiders transforming an Orb-Web into a cocoon web, is to see how much this transformation effects the whole behaviour of the structural system. It shows, that depending on how you (re-)organise threads in space, you can achieve various characteristics of the construction.

Thinking of fibrous structures in space not as a final stage of structural identity but as a system that is open for transformations and adaptions opens up the possibilities of multiple scenarios of novel morphological concepts including optimization and ongoing structural change.

Depending on which material and fabrication process one wants to use, the structure can change from one kind to another one within a short time-period. The set-up can have multiple and flexible functions, and may adapt accordingly between them. This opens up multiple ways of how not only urban spaces can be used more effectively.

As we already discussed in Chapter 05, a very crucial part of adapting the Zombie Spiders’ transformation process to an architectural scale is the material used.

The most unambiguous translation would be a fibrous structure that is composed out of fibers that are elastic up to a certain point. This means, that the structure can be fully transformed without changing the anchorings of the threads. The system plays with tension and looseness of the fibers which defines the structural behaviour inside of a dynamic, flexible up to a very static and stiff system. This could be interesting in constructions that need to somehow react to heavy environmental influences, changing loadcases and alternating functions. The elastic fibers allow for a back and forth change and continuous adaptation. Their is no final state, but a possibility to change between a infinite number of configurations.

However, in our further investigations for technical applications we constrained ourselves to a specific setup with the used fibers being preimpregnated carbon rovings with an unmanned aerial vehicle (UAV) as transportation system and industrial robots for the exact placement of the fibers. At the one hand, this scenario is very specific and restricting, as the carbon fibers are going to cure within a certain timespan and are not open for transformations after they reached that final state. But at the other hand it comes very close to the most recent technical possibilities of how to work with fibrous systems in a big-scale fabrication scenario in the very near future. Even more, there is still the possibility to transform the morphology of the structure between the first placement of the fiber and the start of the curing process. And the impregnated carbon fibers make possible a shift from tension-only to compression structures as soon as they are cured.
Chapter 07: WHY?
WHY ARE THESE TRANSFORMATION STRATEGIES INTERESTING?
What we were most interested in terms of transformations of a carbon fibrous structure is the state change from a loosely put and undefined system of threads that are put into place by a somewhat unprecise UAV, to a defined and controlled form.

In all possible scenarios of how a drone could construct a fibrous construction one needs to deal with a maximum accuracy that is dependent on the fabrication space, but will not soon be below multiple centimetres, if not even a few decimetres. That means that whatever structure a drone is building, inaccuracy is either accepted and welcomed, or there is a system needed that is able to transform these loosely put threads into another, completely differently behaving structure. Having the power of controlling the position of each of thousands of threads in 3D space is not only interesting in an aesthetic point of view. We reach the core of these possibilities as soon as we think about structural performance and material efficiency.

In the biological investigation we clearly identified these two factors as the main drivers for the transformative change from an orb web to a cocoon web. Even though these relationships are quite complex and hard to understand, we also had the chance of doing a structural analysis which seems to support this state of the art in biological research. The most apparent and logical way of describing the importance of this change and the reason why the cocoon web is behaving so much better in structural efficiency, is the logistics of a tension equilibrium. An orb web has no use for a tension equilibrium, as it needs to most importantly deal with dynamic forces. The concept of dealing with an impact is X times higher than the material strength of the single threads in the system, a scenario where only minor impacts are reduced to a minimum. Concerning the material efficiency in a static load-case scenario of a fibrous system it is very important that all forces are distributed to all the thousands of fibers in a homogeneous way. Dealing with a static load that is X times higher than the material strength of the single threads in the system, a scenario where only minor amount of fibers is structurally effective at the first place will result in the failure of these, and incrementally of the whole structure.

To avoid this failure spiders have developed strategies of creating a tension equilibrium in the cocoon web. Threads that are only loosely hanging in space are tensioned with very simple techniques like the concept of bundling two fibers together in order to make both of them more tensioned.

We see a lot of potential in the application of similar bundling techniques with carbon fibers, because also there the tension equilibrium in the structure is of crucial importance.
Chapter 08: HOW?

HOW CAN FIBROUS MORPHOLOGIES BE TRANSFORMED?
Looking into the microscopic images of how spiders in nature actually bundle two silk threads together, we discovered that in some species fibers are wound (FIGURE 8_1) and in other species fibers are glued biologically (FIGURE 8_2). A common feature among most of the spiders is that they use bundling strategy to tension the existing fibers and control the position of joints, thus transforming the whole web structure’s morphology.

As discussed in Chapter 4, we can conclude that Zombie Spiders control the tension in their net-structure mainly by bundling two fibers, connecting two fibers and combinations of these two strategies. We abstracted three typical transformation strategies shown as below:

1. BUNDLING.
   Basically two fibers are bundled together into one stronger fiber, thus the two slack fibers get more tensioned and much stiffer. This is the preliminary transformation strategy. When we turn that into architecture, considering the bundling technique, we choose winding two or more fibers together to tension the system and reach a similar effect.

2. CONNECTING.
   If two fibers in space are far away or when there is a need of stabilizing the structure, Zombie Spiders also connect two fibers with an additional fiber. In architectural scale, we add additional fibers as well, to connect two distanced fibers.

3. BUNDLING + CONNECTING
   In spider net structures combinations of bundling and connecting strategies are most commonly observed. These transformations form a certain geometrical pattern and have a great potential in architectural scales.
WINDING AS BUNDLING TECHNIQUE

Given the fact that bundling is a very important strategy to transform the Zombie Spider’s net-structure, we believed that the bundling strategy should also be the main transformation method of this project.

But considering the different fibrous material properties between silk and carbon fiber, it is not a simple copy-paste transfer, since spider silk can get deformed after bundling due to its elasticity, whereas carbon fibers do not allow such deformation.

Trying to bring the bundling techniques of the spider into an architectural scale we therefore needed a way to compensate the elastic behaviour at the anchor points of the threads.

That means that while two fibers get tensioned, we also need to feed fibers to guarantee a controlled winding process. During these studies, we found that by controlling the feeding speed and feeding force, we can actually control the winding direction, thus controlling the position of winding joint in space as a spider would do by moving along the threads.

FIGURE 8.5: Stretching and Feeding. (Source: Jingcheng Chen, Dominga Garufi, Dongyun Liu, Hans Jakob Wagner)
Position Controlling

We discovered that by controlling the feeding speed and force we can actually control the position of the winding point. This offers a big potential in global design and a bottom-up transformation. *

(*) Using this winding methodology, we created different setup to explore the potential of position controlling. Refer to appendix to see more information.(FIGURE 9_5)
ANSYS SCRIPT

!cocoon_web, dead_load
finish
! --------solve--------
acel, -1
d, 20, all
d, 8, all
d, 24, all
d, 36, all

!cocoon_web, dead_load
finish
! --------element--------
et, 1, link10
alrf

type, 1
mat, 1
real, 1
d, 4, all
d, 6, all

type, 1
mat, 1
real, 1
d, 5, all

! -------nodes---------
ua = 2*pi/20
*d,o,1,1.2
n, i, 4, 3.033*cos(ua(i-1)), 0.0033*sin(ua(i-1))
n, i, 4, 3.0367*cos(ua(i-1)), 0.0087*sin(ua(i-1))
n, i, 4, 3.031*cos(ua(i-1)), 0.01*sin(ua(i-1))
*enddo
n, 61, !!!!!!!!!!!!

! --------element-------
et, 1, link10
alrf
type, 1
mat, 1
real, 1
*do,j,1,19
e,i,1
*enddo
ee,20,1
*do,j,21,39
e,i,1
*enddo
e,40,21
*do,j,1,20
e,61,1

!-------nodes---------
e, i, j, 1, 20
e, i, j, 40
*enddo

!-------solve--------
acel, -1
d, 41, alld
d, 50, all
d, 60, all

type, 1
mat, 1
real, 1
d, 60, all

! -------nodes---------
e, i, j, 1, 20
e, i, j, 40
*enddo
FIGURE 9.2: Sketches. (Source: Jingcheng Chen, Domingo Garule, Dongyuan Liu, Hani Jakob Wagner)
**FIGURE 9_3:** Carbon Fiber Axial Tension Test. (Source: Jingcheng Chen, Dominga Garufi, Dongyuan Liu, Hans Jakob Wagner)

**FIGURE 9_4:** Exploration of local web configuration. (Source: Jingcheng Chen, Dominga Garufi, Dongyuan Liu, Hans Jakob Wagner)

**CHAPTER 09: APPENDIX**

Test 1
2 fibers wound together

Test 2
2 fibers wound together (with fork)

Test 3
2 straight fibers

Failure at ends

Axial tension test

A: COMPARISON
B: TENSIONING
C: CONNECTING
D: CONNECTOR

Name: TENSIONING FORMING
Category: LINKING
3 subsequential steps
CHAPTER 09: APPENDIX

**FIGURE 9.4:** Exploration of local web configuration. (Source: Jingcheng Chen, Dominga Garuñ, Dongyuan Liu, Hans Jakob Wagner)

**FIGURE 9.4:** Exploration of local web configurations. (Source: Jingcheng Chen, Dominga Garuñ, Dongyuan Liu, Hans Jakob Wagner)

**FIGURE 9.4:** Exploration of local web configuration. (Source: Jingcheng Chen, Dominga Garuñ, Dongyuan Liu, Hans Jakob Wagner)
FIGURE 9.5: Exploration of Winding System. (Source: Jingzheng Chen, Dominique Garoff, Dongyuan Lü, Hana Jakobi Wagner)

FIGURE 9.6: Reconstruction process of a 3D model of the resting web of L. mariana based on two images taken in the field by Eberhard WQ (2015)
CHAPTER 09: APPENDIX

FIGURE 9.7: Speculative Design 1 Using transformation techniques to controllably create connection points of threads onto inflatable formwork (Source: Dongyuan, Garufi, Jingcheng, Wagner)

FIGURE 9.8: Speculative Design 2 Scaffolding structure that is controlled by developed transformation strategies (Source: Dongyuan, Garufi, Jingcheng, Wagner)

FIGURE 9.9: Speculative Design 3 Using transformation techniques to create network of structural threads, being tensioned and connected by developed transformation strategies (Source: Dongyuan, Garufi, Jingcheng, Wagner)

FIGURE 9.10: Speculative Design 1 Using transformation techniques to controllably create connection points of threads onto inflatable formwork (Source: Dongyuan, Garufi, Jingcheng, Wagner)

FIGURE 9.11: Speculative Design 3 Using transformation techniques to controllably create connection points in a 3 Dimensional Fabrication Space (Source: Dongyuan, Garufi, Jingcheng, Wagner)

FIGURE 9.12: Speculative Design 1 Using transformation techniques to controllably create connection points of threads onto inflatable formwork (Source: Dongyuan, Garufi, Jingcheng, Wagner)

FIGURE 9.13: Polysphinctine Wasp Flacopimpla barathrica sp. (Source: NR Früzen (2014))

FIGURE 9.14: Immature stages of H. bicolor and their effects on their hosts. (Source: Gonzaga, Eberhard, Sobczak, Penteado-Dias (2010))
References

1. Eberhard WG (2000a), Spider manipulation by a wasp larva
2. Sobczak, Loffredo, Penteado-Dias, Gonzaga (2009), Two new species of Hymenosipmex (Hymenoptera: Ichneumonidae: Pimplinae) with notes on their spider hosts and behaviour manipulation
3. Sobczak, Loffredo, Penteado-Dias, Carmagas (2012), Hymenosipmex neotropica (Bues & Richardson) (Hymenoptera, Ichneumoni- dae, Pimplinae) parasitoid of Anaruae omnimoda (Keyserling) (Anaruae, Anaraidae): first host record and new occurrence to Brazil
5. Takasuga, Yasui, Ishigami, Nakata, Matsumoto, Ikeda, Maeto (2015), Host manipulation by an ichneumonid spider ectoparasitized that takes advantage of preprogrammed web building behaviour for its cocoon protection
7. Korenko et al. (2015), Modification of Tetragenatha montana (Anaruae, Tetragmeidae) web architecture induced by larva of the parasitoid Acrotylus quadriquadratus (Hymenoptera, Ichneumonidae, Polysphincta genus-group)
10. Gonzaga, Eberhard, Sobczak, Penteado-Dias (2010), Modification of Nephila clavipes (Anaruae Nephilidae) webs induced by the parasitoids Hymenosipmex biconor and H. Robertean (Hymenoptera Ichneumonidae)
14. Miller, Belgis, Beentjes, Zewials, van Heelvingen (2010), Spider hosts (Arachnida, Anaruae) and wasp parasitoids (Insects, Hymenoptera, Ichneumonidae, Ephesina) matched using DNA barcodes
15. Pritsin, Suh (2014), On the spider parasitoids Polyphinctes longa Kasparyan and P. boops Tschek (Hymenoptera, Ichneumonidae, Pimplinae), with the first host records of P. longa
16. Gonzalez et al. (2013), Changes to web architecture of Leucauge vulgate (Anaruae: Tetragnathidae) induced by the parasitoid Hyme nosipmex potanini (Hymenoptera: Ichneumonidae)
18. Blackledge, Coddington, Gillespie (2003), Are three-dimensional spider webs defensive adaptations?
19. Eberhard (2010a), Recovery of spiders from the effects of parasitic wasps: implications for the tuned mechanism of manipulation
27. Conversation with Eberhard WG (2010)