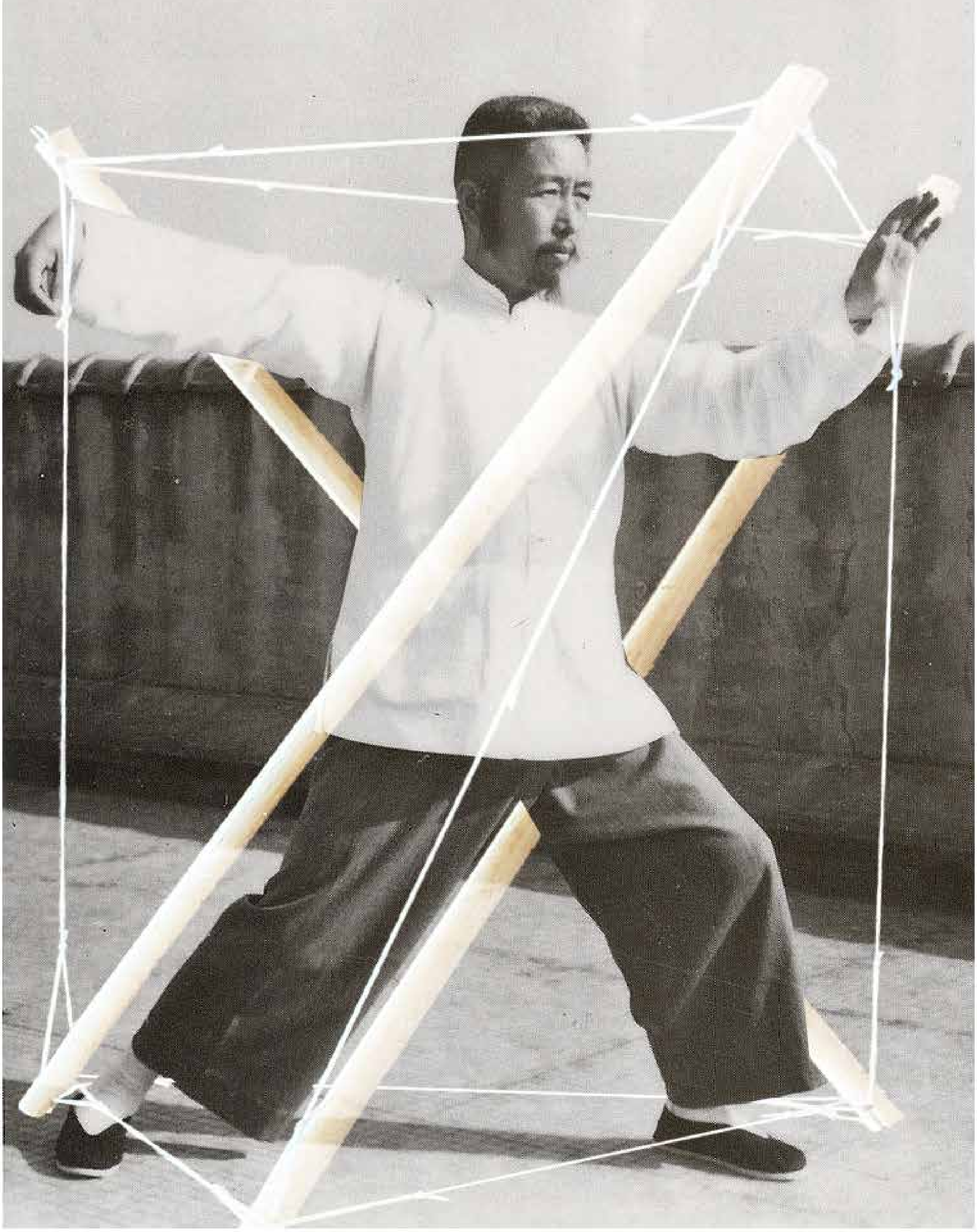
THE ART OF BALANCE

Exploring Analogies in Taiji Forms and Tensegrity Structures



平衡的艺术：探索太极拳形态与张力平衡结构中的类比

Adrian Koziol, Dipl.Ing.Arch.

Author: Adrian Koziol
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Source: Wikimedia Commons, date 10.01.1922; Photo montage by the author
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摘要

Abstract

This essay explores the analogies between Taiji (short for T'ai Chi Chuan), an ancient Chinese martial art, and Tensegrity, a structural principle that utilizes tension and compression to create self-supporting forms. The investigation focuses on how characteristics of Tensegrity—such as discontinuous force distribution or the maintenance of self-equilibrium—relate to the movements and philosophy of Taiji.

Based on five core Taiji principles, the properties and behavior of self-built Tensegrity models are examined and compared to Taiji principles and their significance for the practice.

This analysis further provides insights into the parallels between Tensegrity structures, natural systems, and human biomechanics, emphasizing the role of soft, non-linear systems.
Given the surprising effectiveness of softness in Taiji movements, this work aims to contribute to a more systematic understanding of Taiji practice.

Ultimately, this essay highlights the shared principles of harmony and efficiency in Taiji and Tensegrity, offering new perspectives on the interactions between physical movement and structural dynamics.

摘要

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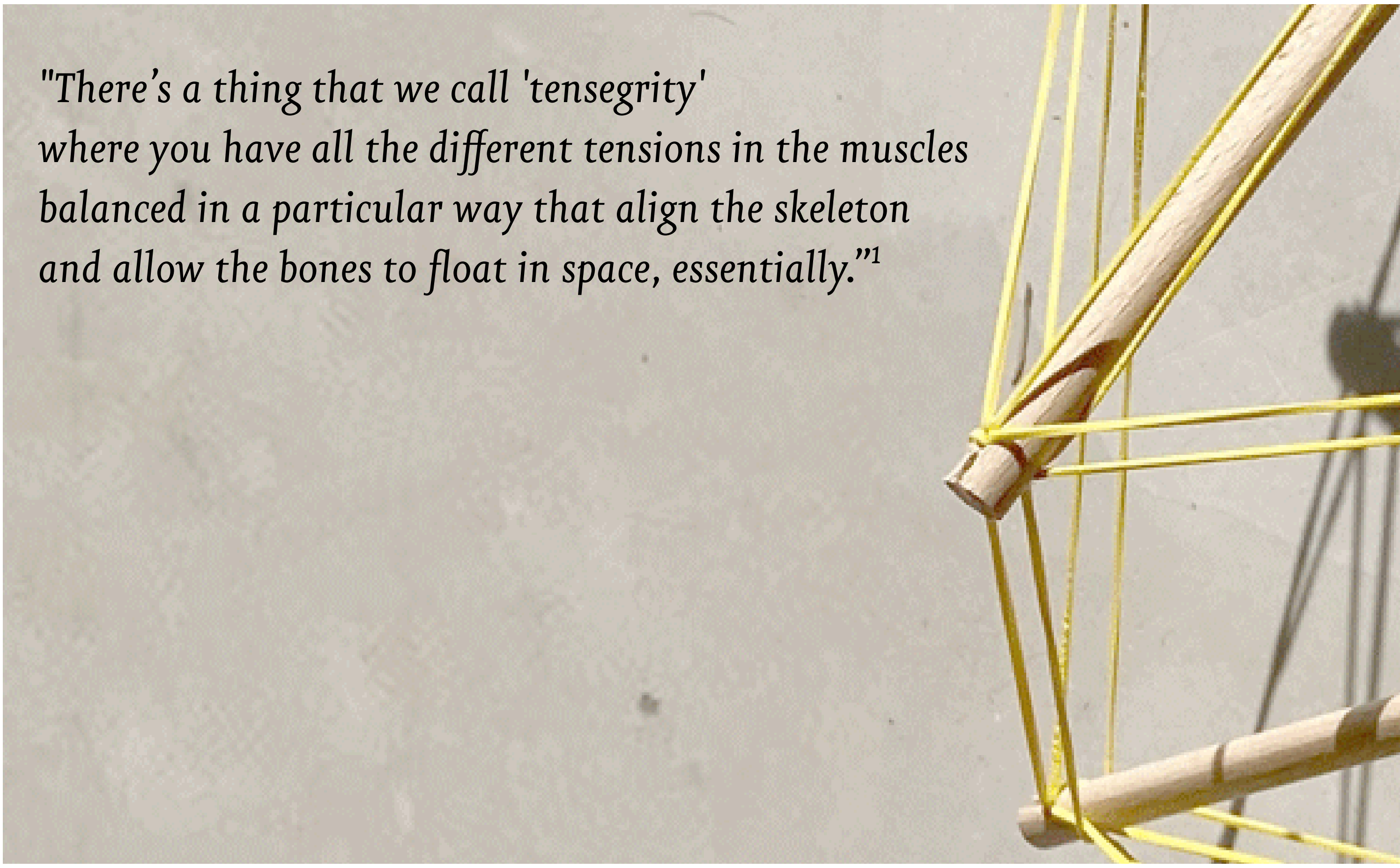
Analogy in Taiji & Tensegrity



> *"There's a thing that we call 'tensegrity'*
> *where you have all the different tensions in the muscles*
> *balanced in a particular way that align the skeleton*
> *and allow the bones to float in space, essentially."*[1]

前言

Preface

The quote above is taken from Ian Sinclair's video *The Magic of Alignment in Taiji*[1] and marks the beginning for my Taiji Teachers Project in Norway under *Pamela Hiley*[2] in 2022/23.

My aim for this project was to explore a possible connection between Taiji and a structural principle called Tensegrity. Tensegrity? I first heard about this structural principle during my architecture studies — a structure that remains stable in itself, even though the load-bearing elements are not directly connected. This form of architecture is known as Tensegrity because of its dependence on tensional integrity. But unfortunately, I didn't give it any further attention. And so, the years passed without Tensegrity ever crossing my path again, neither in architecture, nor in society, nor in nature. In general, you can say that the knowledge around Tensegrity was not present in my life. But once I began to dig deeper, I was amazed by how many connections and relationships Tensegrity unveiled. My project became increasingly influenced by the information I gathered from various fields, such as geometry, philosophy, biology or human biomechanics.
Is our skeleton a kind of tensegrity structure? Are there smaller tensegrities within every biological cell? There seemed to be countless articles on the internet linking tensegrity or biotensegrity. Many of them were illustrated with tensegrity models. Some models were very simple, others more complex, but they all shared a certain natural aesthetic. (A nice overview with many images can be found on Marcelo Pars Tensegrity website[3])

But how could I build them? Following video tutorials, I recreated a simple three-rod Tensegrity model. But with four rods and no guide, I was lost—complex theories didn't help either. Building one on my own felt impossible because I didn't yet grasp the principles.
And just like Taiji, understanding comes through practice. After countless attempts with wooden rods and rubber bands, I solved part of the puzzle—but there was still much to learn, especially in connecting it to Taiji.

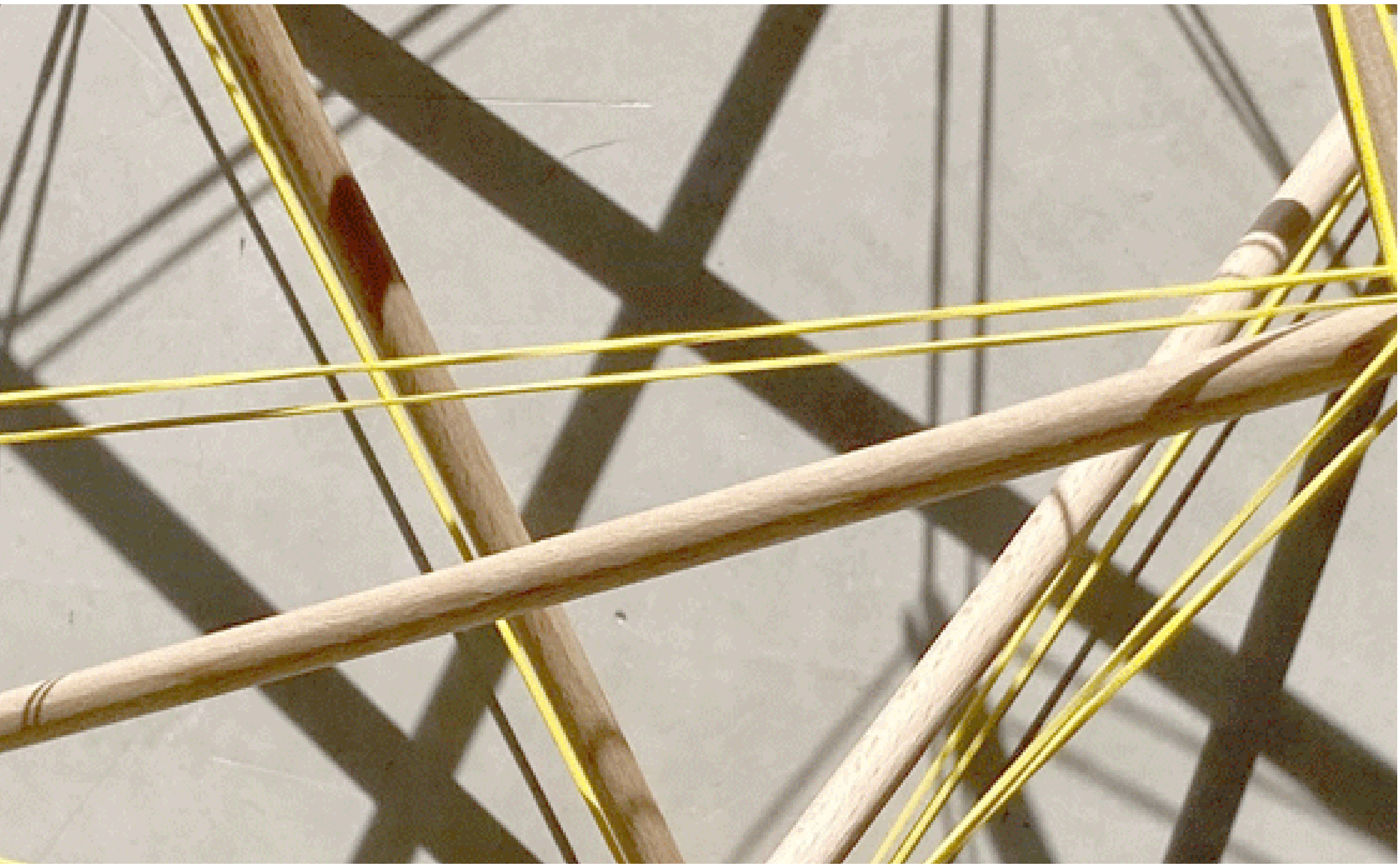


Fig. 4.1; Tensegrity model with wooden rods and rubberbands by the author

Taiji is known as an ancient Chinese martial art system for health and self-defense, providing spiritual, mental, and physical well-being. The knowledge of Taiji was primarily passed down over centuries through oral tradition, practical training, and direct instruction from generation to generation. In some cases, the principles and philosophies of Taiji were recorded in written texts. In the so-called *Taiji Classics*[4], one can find phrases such as:

"With every movement string all the parts together, keeping the entire body light and nimble"

In a way, these description could also apply to tensegrity and seem to share underlying similarities.

Professor *Cheng Man Ching*[5] (pictured on the cover) is a central figure in bringing Taiji to the West. His modern version, with 37-forms of Taiji movements, influenced his students, such as *Benjamin Lo*[6] (pictured on page 5) who emphasized the *Five Basic Principles* for developing good Taiji skills. This very type of Taiji quintessence provided a well-structured foundation to start my exploration.

This work begins with a brief overview of the Five Basic Principles, followed by an introduction to Tensegrity and my experience with model building. Rather than providing detailed explanations, this work highlights key insights, with notes linked on the last page.

Tensegrity structures express internal forces in their purest form. This study does not seek to replicate force vectors in the body but rather explores whether the shapes formed in Taiji can be recreated using self-supporting Tensegrity structures.

Because Tensegrity can be difficult to grasp—even images or illustrations may not always fully explain it—I have added QR links to videos at the end of the relevant sections to document my studies.

From here, I invite the reader to explore the interesting connections between Taiji and Tensegrity, where theory and practice come together, revealing new insights along the way.

*"With every movement string all the parts together,
keeping the entire body light and nimble".
Tai Chi Classics*

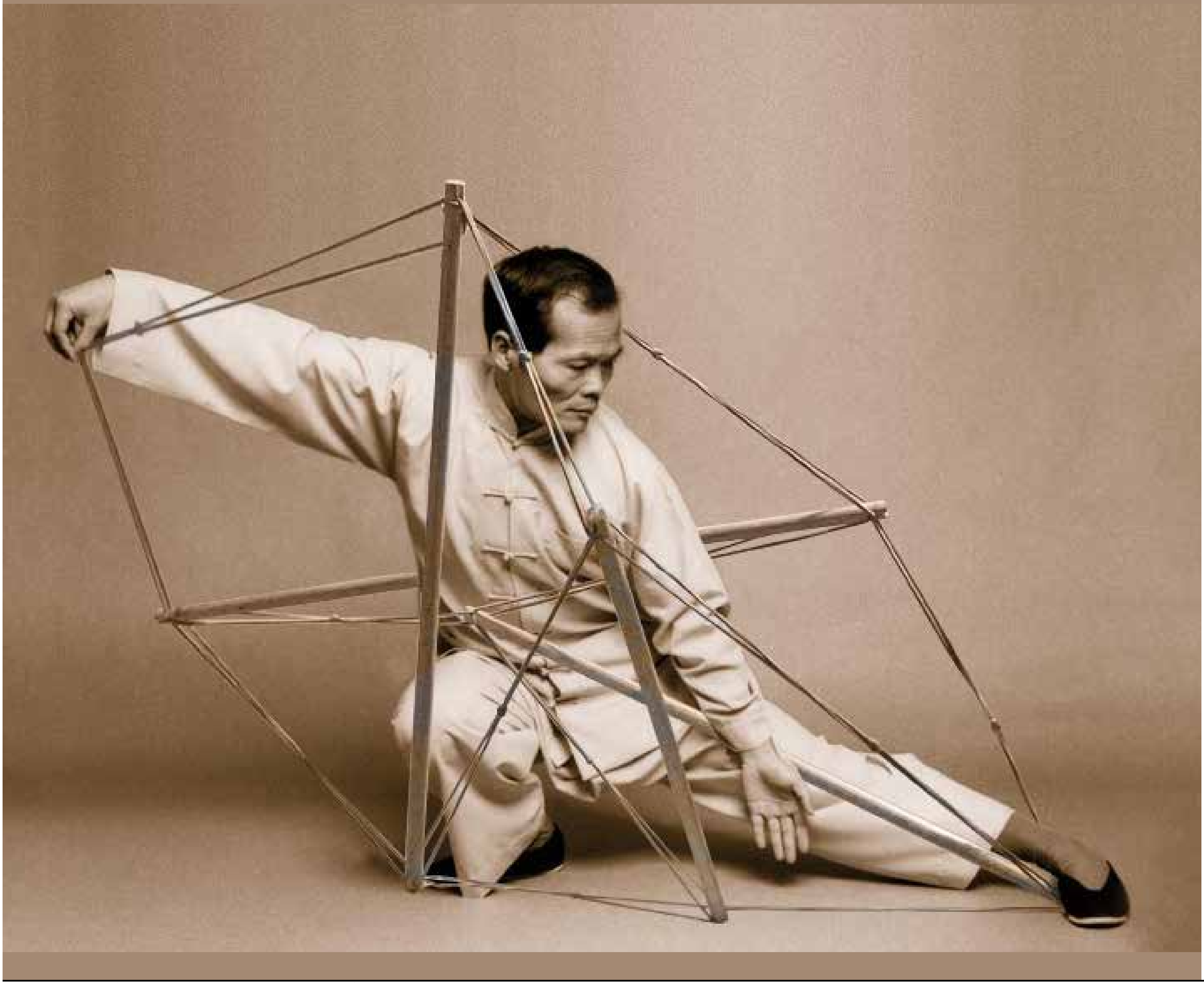


Fig. 5.1; Original picture showing *Benjamin Lo* in the 'Snake Creeps Down' posture; modified and photo montage by the author.

太极：五个基本原则

Taiji

The 5 Basic Principles

Benjamin Lo[6] was known for his insistance upon the five prime principles of Taiji. He taught these principles to his students across the U.S. and Europe, including my Taiji teacher Pamela Hiley, constantly highlighting the importance of regular practice and relaxation as the foundation of Taiji. His teachings were rooted in his deep respect for Cheng's methods, which he actively defended throughout his life.
Bellow a short summery by the author:

1. Relaxation

Relaxation in Taiji is also described by the Chinese word *Sung*. It refers to a state of relaxed alertness or softness in the body. It involves the release of tension, allowing the body to remain loose and supple while maintaining structure and alignment. The state of *Sung* is fundamental to all other principles and is crucial for promoting energy flow, balance, and efficient movement in Taiji.

2. Separate Yin from Yang

Also known as *Separate the weight*, this principle focuses on the correct distribution of body weight during Taiji movements. When the body's center rests on one leg, then that leg becomes solid (yang), while the other leg is empty (yin). By clearly distinguishing between these states, our movements will become light, agile, and effortless.

3. Flexible waist

The waist is considered the *Commander* in Taiji. All movement originates from the waist, whether it is a hand movement or a step. The waist is where the downward push of gravity meets the upward push of the legs. From this point, it directs the flow of energy through the body, determining its direction.

4. Body upright

Proper alignment between the head and the spine is crucial for transmitting power between the shoulders and hips. The spine can act as a spring that connects these two points. It can be either stiffened, allowing force to be transmitted up and down, or relaxed, enabling the spine to twist and turn. To be effective in both functions, the spine must be properly aligned.

5. Beautiful Ladies Hand

The hands are part of the *shoulder-elbow-wrist connection*[7]. When the shoulders are properly connected (through the spine), force can be efficiently transferred from the hand through the spine to the legs and into the ground, and vice versa.
For this reason, the wrists should never be limp; The hand should be 'alive' but relaxed, maintaining a naturally straight and intentional posture.

VL1 : Youtube
Ben Lo's 5 principles
(a good presentasjon by
Rocky Mountain Tai Chi)

"The universe is the result of nothing but forces."
Kenneth Snelson

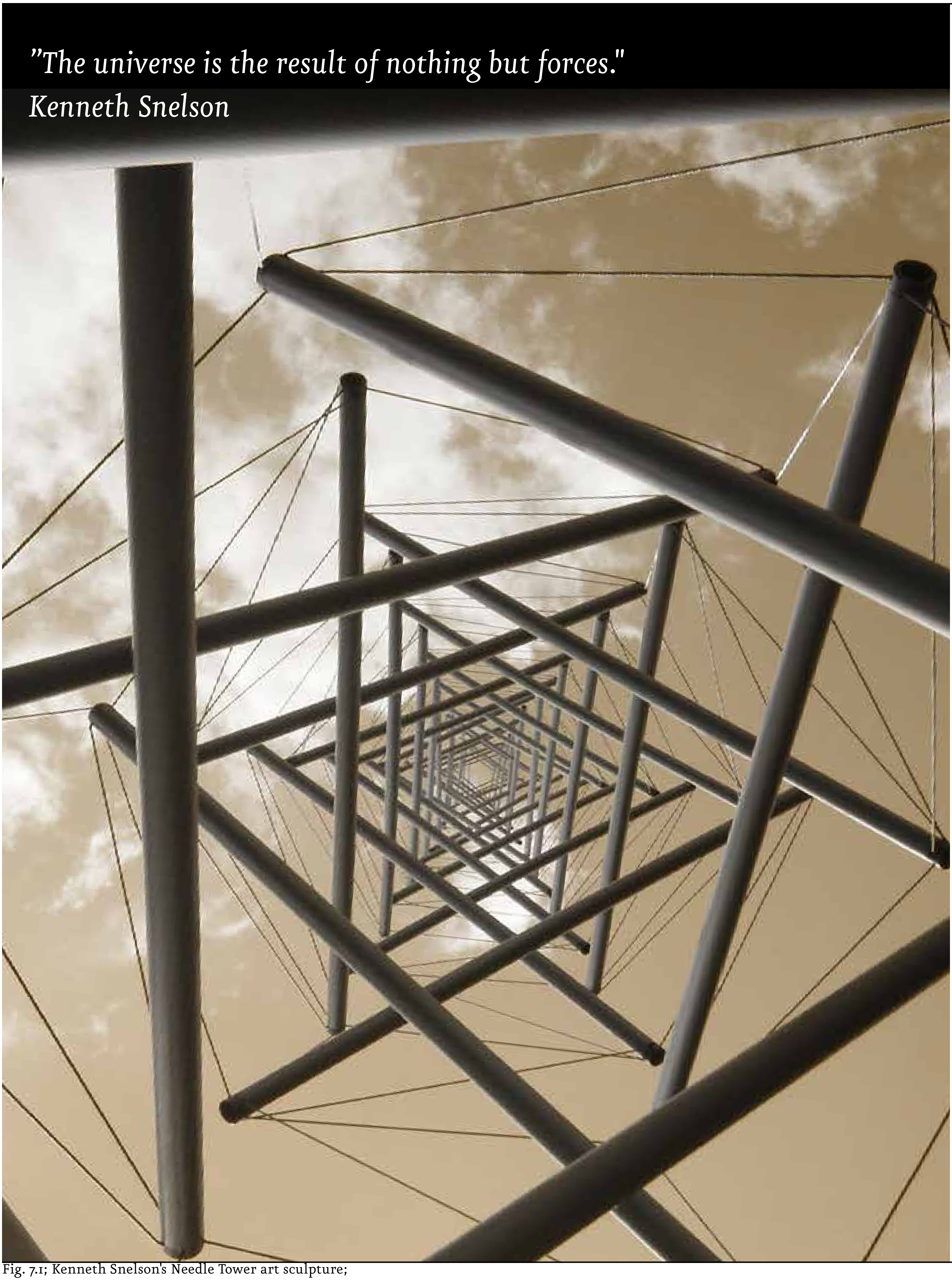


Fig. 7.1; Kenneth Snelson's Needle Tower art sculpture;
Looking up from the inside; Source: Wikipedia.org

张力平衡：张力与结构的整体协调

Tensegrity

Tensional Integrity

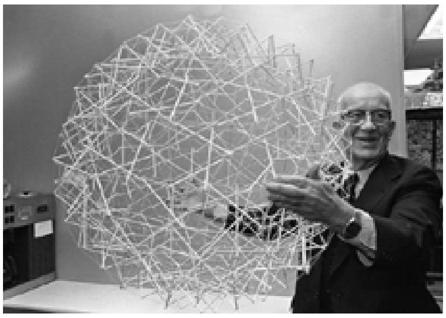


Fig. 8.1
Buckminster Fuller holding a tensegrity sphere.

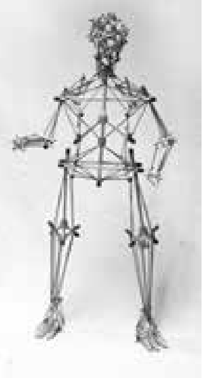


Fig. 8.2
Tensegrity skeleton;
by Tom Flemons [16]

Fig. 8.3
Snelson's Needle Tower;
Foto: Jim Henderson

Fig. 8.4
Cover of Scientific American Magazine (1998), illustrating Donald E. Ingber thesis about tensegrity and the cells, which have cytoskeletons that hold them together and allow to them to move.

Tensegrity[8] is based on the principle that tension and compression are necessary to create a stable structure. It was first described and pioneered by architect *R. Buckminster Fuller*[9] (Fig.8.1) in the late 1950s, and first visualized by sculptor *Kenneth Snelson*[10]. During the same period, French architect *David G. Emmerich* was studying similar structures.
The Tensegrity concept, (hereafter called TS), quickly became familiar to structural engineers and architects through a variety of applications. Figure 7.1 and 8.3 showing Kenneth Snelson's *Needle Tower II* (1969). Snelson preferred the descriptive term *floating compression* for his work. The bars appear to float in the air, with no contact to a solid support. By examining the realizations of *Snelson*, *Buckminster Fuller*, and *Emmerich*, we can compile the following list of defining properties:

Continuous Tension (cables form a connected set)
Discontinuous Compression (no two bars are ever connected)
Pre-stressed (frameworks are stabilized by a state of self-stress)
Self-equilibration (distribution of stress while maintaining structural integrity)
Minimalism and Efficiency (achievement of maximum strength with minimal material)
Scalability and Modularity (ability to adapt different sizes and configurations)

These characteristics form the basis for *Biotensegrity*[11], a concept introduced by *Stephen M. Levin* in the late 1970s, where TS principles are applied to biological structures. In this model, the body functions as a TS-system, with bones acting as compression elements and muscles, tendons, and fascia providing tension (Fig.8.2). This holistic view emphasizes the dynamic balance of tension and compression throughout the body, enhancing stability, flexibility, and efficient movement.

In the early 1990s, *Donald E. Ingber*[12] advanced the idea of Tensegrity, adapting its principles to explain cellular structures. In *The Architecture of Life*, Ingber showed that TS principles govern not only the musculoskeletal system but also molecular structures, where proteins and other components maintain stability through similar tension-compression dynamics (Fig. 8.4).

Understanding biotensegrity provides valuable insights into how our bodies function as interconnected systems of continuous tension and discontinuous compression.

In current research, the use of tensegrity systems still remains of great interest in the field of biology as well as in robotics, particularly for space applications.

”Likewise, upward and downward, forward and backward,
Leftward and rightward – these are to be directed by the
Mind-Intent and are not to be expressed externally”.
Tai Chi Classics

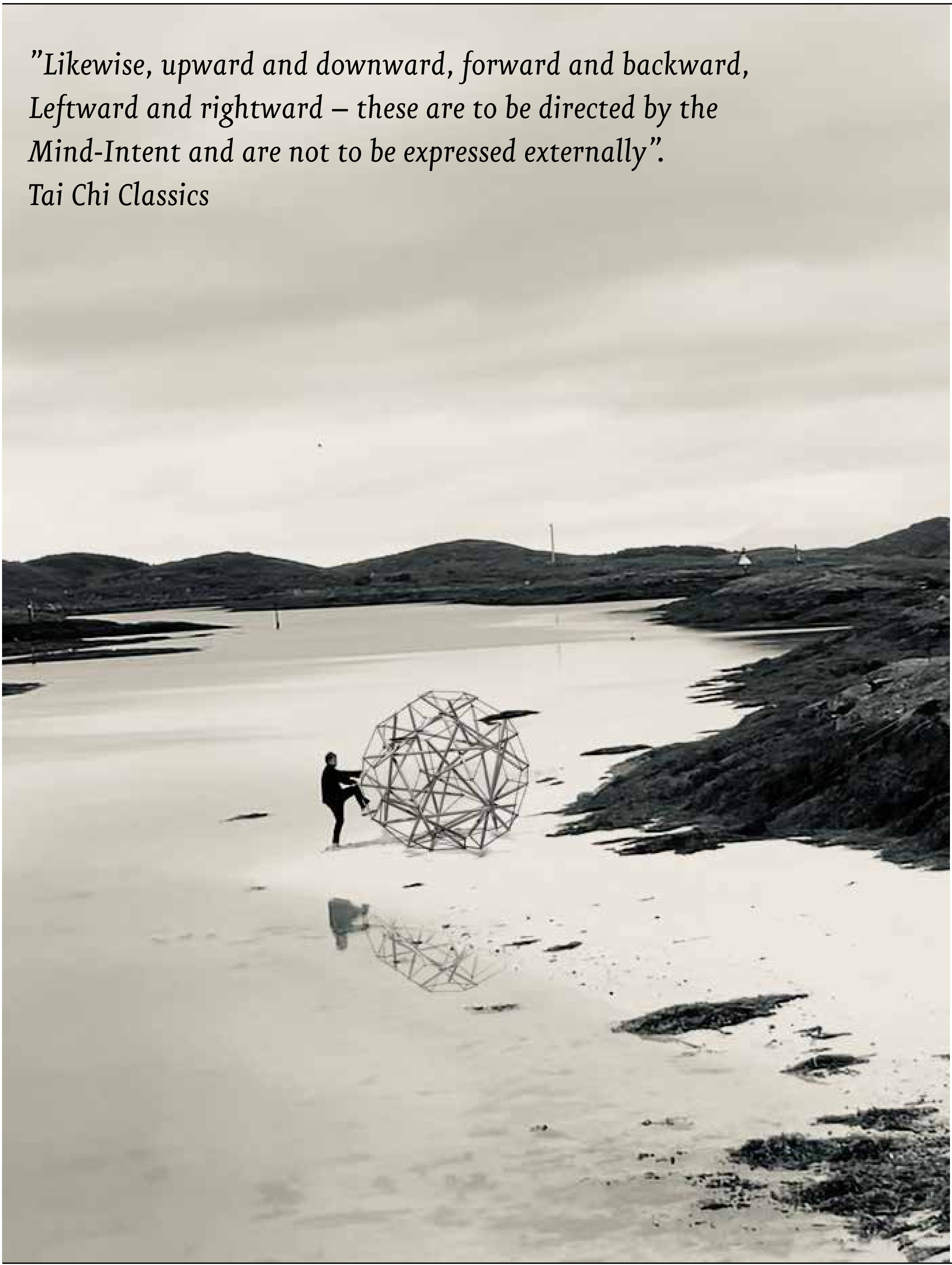


Fig. 9.1; The author practices Taiji in northern Norway.
Photo montage by the author

模型构建：通过物理模型的反思与学习

Model Building

Reflections and Learning through Physical Models

It would be challenging to create a TS-model due to its external shape. Unlike other geometric structures that can be built by adding pieces one at a time, a TS-model doesn’t take shape until the last rod is connected, and all parts are held in tension. Constructing such models requires knowledge of geometry, methods for connecting and adjusting tendons, as well as precalculated lengths for each element.

Right from the start, the challenge is to flexibly link compressive and tensile elements – essentially, creating a reversible connection between a rod and one or more tendons. By small holes at each end of the wooden rods, accessible through sawn cuts (Fig. 10.1), I was able to attach prepared tendons, such as rubber bands or ropes. The hole allowed the bands to be fixed in place, while at the same time, they could easily be inserted or replaced through the sawn cuts with others of different lengths if necessary. This flexibility is crucial, as accurate length ratios are essential for the success of any TS model. It is possible to calculate these lengths mathematically[19]; however, even for the simplest TS model with 3 rods, this results in a very complex calculation. For this reason, I preferred a simpler ratio method (1 rod to 1.5 tendons), followed by subsequent adjustments. For instance, a 25 cm rod would require tendons of 37.5 cm.

Starting from a planar triangular shape with three rods (three corners and three edges = equal ratio), we create an unequal corner-edge-ratio and subdivide it into multiple smaller triangles by conceptually dividing the rod lengths. (Fig. 10.3)

During assembly, all segments are connected from endpoint to endpoint using tendons. Each tendon triangle links to the next via a rod and two tendons. Finally, additional tendons connect the outer endpoints (Yellow arrows in Fig. 10.4). This step feels like stretching the 2D pattern over an invisible sphere. Not until the last connection is made (Fig.10.5) do all tendons stabilize, and the 3D shape emerges as if by magic (Fig. 10.6).

A new state and a new form have been created, comprising a discontinuous set of compressed rods within a continuum of tensioned tendons, bringing new properties and possibilities that we will explore in more detail on the following pages.

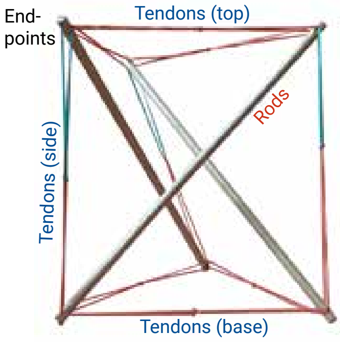


Fig. 10.7; Tensegrity structures contain a series of isolated compression elements (rods) that resist the pull of surrounding tensile elements (tendons) and impose a prestress that stabilizes the entire network. These structures may contain different size, shape, and number of building elements, and they may be organized hierarchically. Thus they can exhibit a wide range of forms that differ from this simple conceptual depiction.

Fig. 10.1
Detail of the connective endpoints on each wooden rod, prepared tendons in the background

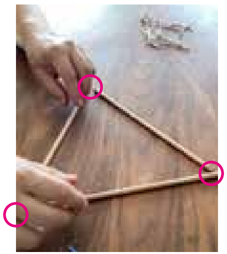


Fig. 10.2
A triangle shape is showing 3 corners and 3 edges (=equal ratio).

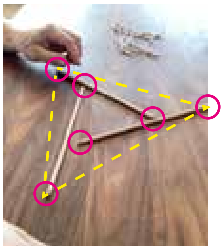


Fig. 10.3
Unequal ratio through triangulation; with 6 corners and 3 edges.

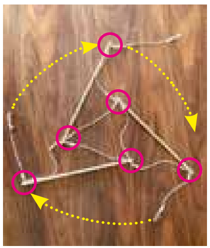


Fig. 10.4
Connecting rods with the tendons

Fig. 10.5
Still no Tensegrity due to one unconnected tendon.

Fig. 10.6
After connecting all tendons, the state of tensegrity occurs.

VL2 : Instagram
See how I build a 3-struts Tensegrity Model.

类比 #1 放松：关于通过低能耗结构实现稳定性

Analogy | #1 Relaxation

About Stability Through Low-Energy Consuming Structure

To discuss *relaxation* through a model may seem unusual, but also exciting. To fully understand its relevance, it is necessary to take a closer look at the term. In our western society, the concept of *relaxation* is often associated with a state of mind or the opportunity to lie down and rest. However, *rest* and *relaxation* are fundamentally different concepts.

Rest is about restoring energy after stressful tasks and is an essential part of life, such as sleeping. *Relaxation*, in contrast, is what we aim to achieve during stressful tasks to reduce the energetic cost of activity. In the context of physical activity, the higher the stress, the more important *relaxation* becomes to avoid wasting energy, improve joint mobility, and increase stability.[13]

In scientific terms, *relaxation* refers to the process of a system returning to equilibrium, which is a state of balance where opposing forces are equal and minimal energy is needed to maintain stability. This principle is grounded in Newton's Law of Motion[14], which explains that an object is always subject to opposing forces.

A person standing on the ground is subject to downward forces caused by their own weight and gravity (Fig.11.2). If the ground cannot generate an equal and opposite force (Ground Reaction Force), the person would sink into the ground. Additionally, the body is constantly influenced by external forces, such as wind or, even more strongly, its own movement. To maintain an upright posture, internal forces within muscles, tendons, and connective tissue are required to stabilize the entire body all the time. To achieve a equilibrium, the body's center of mass must stay above the base of support in such a way that minimizes the internal energy required to maintain this posture.

Through specific adjustments, it is possible to influence and minimize the energy required to come closer to equilibrium. These adjustments can range from significant changes in the position of bones and limbs to micro-adjustments within muscles and connective tissue. Since we feel all parts of the body simultaneously, it is essential to align and adjust all body parts together to achieve balance—not just one part.
For example, when standing upright with straightened legs, the forces are distributed with minimal additional use of the leg muscles. While this posture is efficient for the legs, it increases tension in the back due to a stronger curve in the spine. To achieve better overall equilibrium, it is necessary to support the spine by slightly bending the knees and adjusting the hips (Fig.11.3).

Fig.11.1
This stone has found its equilibrium points at the top of a rounded hill. Since a small displacement of the stone results in a force that moves it away from this equilibrium point, we call this situation "Unstable equilibrium."

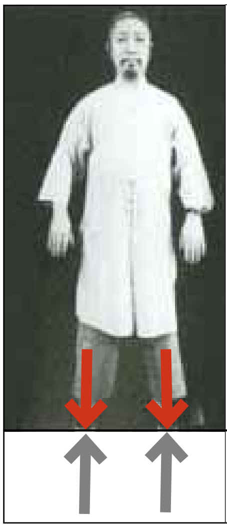


Fig.11.2
Front view of Wuchi. Downward forces (red) meets opposite forces (Ground Reaction Force)in the ground (grey arrows).

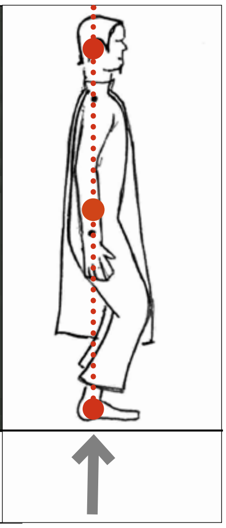


Fig.11.3
Side view of Wuchi-stance, showing center of gravity line and vertically alignment of head, hip (Dantien) and foot.

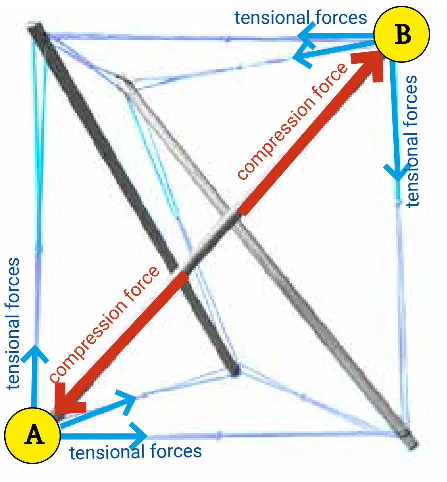


Fig.12.1
Set of forces acting on one rod (between pkt.A and B). Tension element (blue arrows) pulling inards while compression force (red arrows) push outwards.
With right ratio length between rods and tendons the model gets balanced tension in all tendons.

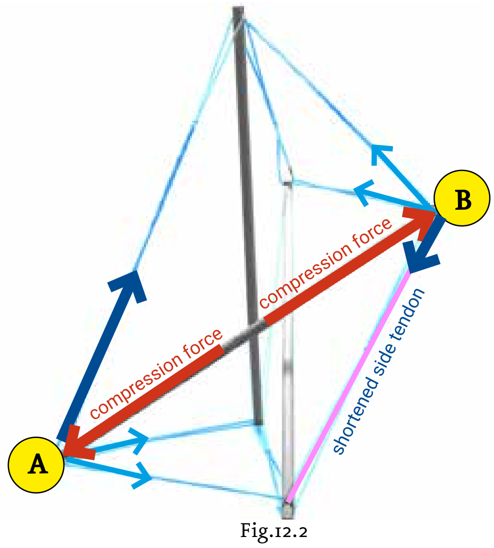


Fig.12.2
Unbalanced set of forces with shortened side tendon on the right side (purple tendon).

A comparable concept in Taiji is the Wuji stance (Fig.11.2), meaning "State of Emptiness." It represents the ultimate relaxation. This starting position prepares both mind and body for Taiji movements. By aligning posture and focusing on the breath, the body reaches a neutral, balanced state between tension and relaxation.

Key points of the Wuji stance:

- Feet & Knees: Shoulder-width apart, knees slightly bent
- Hips: Tailbone tucked in
- Shoulders & Chest: Shoulders relaxed, chest slightly hollow
- Arms & Hands: Arms at the sides, as if holding a ball under the armpits; hands relaxed yet engaged
- Head & Spine: Head upright, as if pulled by a thread; spine straight and elongated
- Mind: Clear, undistracted, with deep abdominal breathing (Dan Tien)

Relaxation is essential for this stance. It cannot be forced. This involves calming both your body and mind. While standing in the ‘Wuchi’ posture might appear simple from the outside, but there is a depth of internal activity that can only be experienced, not observed.

A similar principle applies to TS models. Once the final tendon is connected, even minor tension adjustments can significantly impact the structure. It’s not just about reducing tension but sometimes fine-tuning it.

The simplest tensegrity model consists of 3 struts (wooden rods) and 9 tendon cables (rubber bands). Struts bear compressive forces, while tendons handle tension. In the illustrated TS example (Fig.12.1), compressive forces in rod A-B (red arrows) are counteracted by tensile forces in the tendons (blue arrows). Stability is achieved when all forces balance to zero, preventing movement or deformation. Only in an optimal tension state can maximum stability be maintained with minimal energy—this is the essence of relaxation.

In the video link VL3, you can see how a TS model is gradually corrected, adjusting and changing its form. In the end, the position of the imaginary center is lower and directly aligned with the center point of its base triangle. Indeed, it appears as if the model is sinking into a state of relaxation.

VL3 : Instagram
See how a TS-modell gradually changes to a more stable form.

类比 #2 分离阴与阳：关于清晰定义拉力与压力的好处

Analogy | #2 Seperate Yin From Yang

About the Benefits of Clearly Defining Tension and Compression

To understand this principle, it is important to consider the fundamental ideas of *Yin and Yang* and their relationship within the context of Taiji. The duality embodied by *Yin and Yang* consists of two opposing but complementary forces or principles that inform all aspects of life and the universe. *Yin* represents the passive, soft, dark, cold, feminine, and receptive. *Yang* represents the active, hard, bright, warm, masculine, and giving. These forces are in constant motion and interaction, maintaining a dynamic balance. They never exist in isolation; each always contains a part of the other.

For example, although day and night are opposing states, they do not exist independently of each other. They flow into one another – day transitions into night and vice versa. Even in the darkest night, there is light, whether from the moon or the stars (a small part of *Yang* within *Yin*). Conversely, the day can also contain shadows or moments of stillness (a small part of *Yin* within *Yang*). This constant movement and interaction between day and night illustrate the dynamic balance of *Yin and Yang*, which is never static but always in motion.

In a typical Taiji form, weight is often transferred 100% from one leg to the other. The leg that bears the full weight is considered *Yang* because it is active and stable. The other leg, which carries little or no weight, is *Yin*, as it is passive and empty. This interaction allows movements to be fluid and controlled.

For example, in the movement *White Crane Spreads Its Wings*: (Fig.14.1) The weighted leg is firm and stable (*Yang*), while the unweighted leg is light and ready to move (*Yin*). At the same time, the upper body can combine *Yin and Yang*: one arm remains passive and receptive (*Yin*), while the other is active and giving (*Yang*).

By consciously switching between these states, Taiji creates a harmonious flow of energy that reflects the balance of *Yin and Yang*.

By separating *Yin and Yang*, one can develop a deeper understanding of balance and gain greater control over both body and mind. The form adopts a rhythmic flow and clear direction in both arm and leg movements, enabling the precise release of energy (Qi) at the right moments.

If you look at a TS-model, you will see a *continuous network* of tendons enclosing wooden rods that are placed in a *discontinuous* manner relative to each other. Where there is a rod, there is pure compression, and where there is a tendon, there is pure tension. This allows each material to be used optimally for its specific function: tendons are efficient in handling tensile forces, while rods are particularly resistant to compressive forces. Due to this separation, the structure also requires less mass to achieve stability.

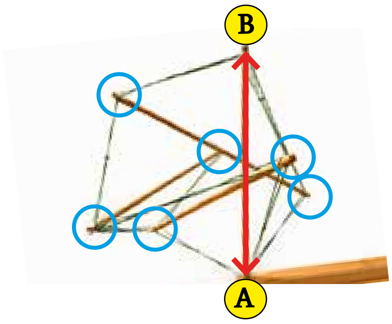


Fig.13.1. 4-struts TS ", *anchored on point A to the ground, simulates a stable part between A og B.*

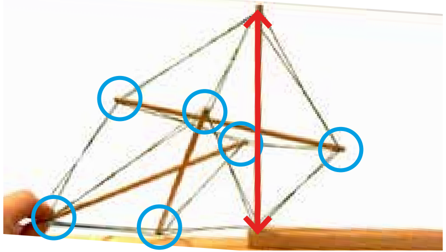


Fig.13.2. *All other points are showing increased flexibility compared to an unattached 4-struts TS-model.*

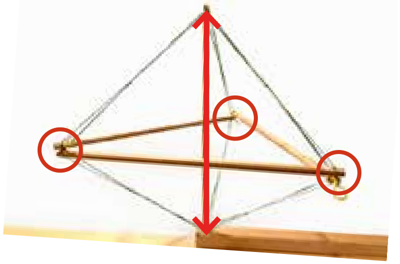


Fig.13.3. *Another 4-struts model which we may not call for Tensegrity because of its 3 points with direct connected struts (red circles).*

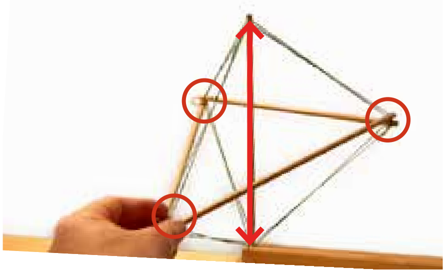


Fig.13.4. *This model is not showing the same flexibility as model in Fig.2.1 and 2.2.*

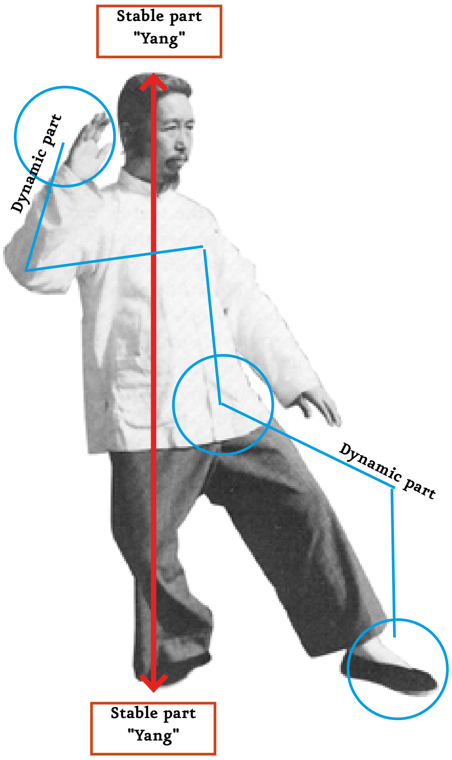


Fig.14.1.
Cheng Man-Ching in the "White Crane Spread its Wings" Positur. In this positur one stands with 100% weight on the right leg.

In traditional construction, loads are often concentrated on a few points or surfaces, which can lead to weak points in the structure. Particularly compressive forces, which occur in massive structures like walls or columns, can lead to deformations, cracks, or even collapse if the load becomes too great. To prevent this, traditional constructions often need to be reinforced, which requires more material and stronger connections. In a TS-System, however, loads are evenly distributed through the network of *continuous tension*, making the structure more resilient and flexible. This flexibility means that the discontinuously placed compression elements can absorb shocks or deformations better without breaking.

TS-Structures exist only through these clearly separated two elements of *continuous tension* and *discontinuous compression*. And like *Yin and Yang*, these two opposing forces must work together. You cannot think of them separately. If you separate them, the structure will collapse.

A model study in this case is intended to simulate a 100% weight shift onto one leg or a stable axis (Yang). I achieved this by firmly anchoring one rod to the underlying table (Fig.13.1). By subsequently applying force with my hand, I aimed to observe and feel the properties of the Yin elements. The result was a remarkably high degree of flexibility and mobility in these parts compared to the original, unattached model (Fig. 13.2).

Furthermore, I wanted to demonstrate how constructions that are similar but not precisely built according to the principles of TS exhibit much less mobility. In this model, I also used four rods and the necessary rubber bands, but three rods were directly connected at their ends to form a triangle (Fig.13.3). This model may resemble a TS-structure, but the direct connection of compression rods contradicts the defining principles of Tensegrity: "No two bars are ever connected," as outlined on page 8. Additionally, the compression rods in this TS system are positioned on the boundary surface. Many Tensegrity purists consider this area to be exclusively reserved for elements where this role is played by tension.
(You can read more about *pure and false* Tensegrities in V.G.Jáuregui's great work about *Tensegrity Structures and their Application to Architecture.*[15])

Compared to a *pure* TS-Model under the same conditions, this *false* TS-model displayed noticeably lower flexibility. This suggests that the discontinuous properties of structures offer noticeable advantages when forces are applied appropriately and consistently.

VL4 : Instagram
See the effect of dynamic elements between a 'true' and 'false' Tensegrity.

类比 #3 灵活的腰部：关于所有组件的协调运动与结构协同

Analogy | #3 Flexible Waist

About Coordinated Movement and Structural Synergy of All Components

The waist is the central part of our body, connecting the upper and lower sections. Together with our spine, it plays a key role in unifying all parts of the body. When the upper and lower body are connected, the entire body can move as an integrated whole: the movement of the legs is coordinated with the movement of the arms, the elbows are coordinated with the hips, and the feet are coordinated with the hands.
The Taiji classic says:
"*If one part moves, the whole body moves.*"

In the taiji positur *Grasp the Bird's Tail* (also known as *Ward Off*, *Roll Back*, *Press, and Push*), for example, every movement you make—whether it's turning your waist, shifting your weight, or extending your arms—activates and involves the entire body. If you were to move just your arms or just your legs without engaging the whole body, the movements would feel disconnected and lack the smooth flow of energy that Taiji aims to achieve.

To explore this principle, we can take a closer look at a tensegrity structure called the *icosahedron* model (Fig.15.1). With its six rods, this model is one of the most well-known tensegrities. It is often used in fields like biology to explain processes in the human body or, more generally, in nature (as seen in the works of D.E. Ingber or S.M. Levin). This model also exhibits mirror symmetry, which makes it easier to identify surfaces within the model (Fig.16.1) and simplifies research, as we are more accustomed to observing straight angles.

When this model is stressed at a specific point, the tension in the tendons and compression in the rods adjust throughout the entire structure. No single part moves independently; instead, all elements of the structure respond to maintain balance.
When two points in the model move apart, the distances between all other parts also expand, creating a state of expansion (Fig.15.2). Conversely, as these points move closer together, the distances decrease, resulting in compression (Fig.15.3). This behavior is especially interesting, as it closely mirrors the two fundamental forces in Taiji, *Peng* and *Lu*, which exhibit similar patterns of expansion and contraction.

Peng (*Ward Off posture, Fig.16.2*) is the force expressed by an increase of tension in the body, which leads to an expansion of all body parts. When one is standing in the correct Peng posture, it is almost impossible to move them, and incoming energy is bounced back.
Lu (*Roll Back posture, Fig.16.3*), on the other hand, is expressed by releasing all tension in order to redirect incoming external energy. This compressive form leads the incoming force into emptiness, causing the opponent to lose balance.

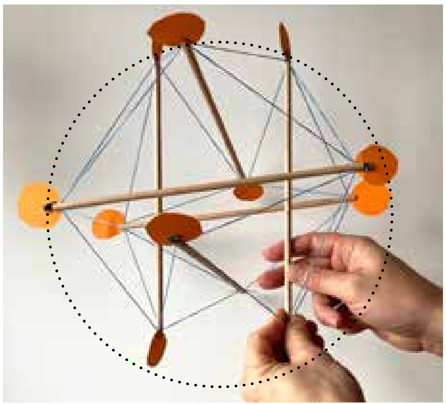


Fig.15.1, A 6-strut TS icosahedron with orange dots at the outer endpoints to emphasize the shell.

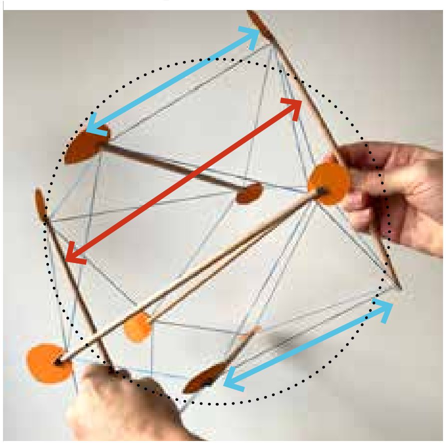


Fig.15.2, In expanding to struts, every orange dot moves outward.

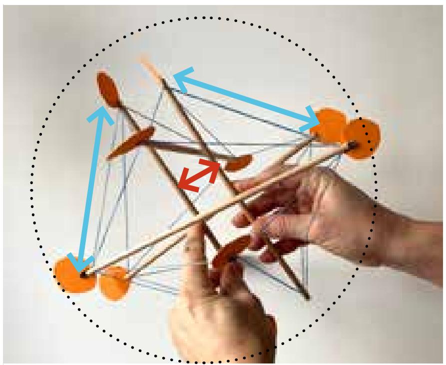


Fig.15.3, When compressing two struts, every orange dot moves inward.

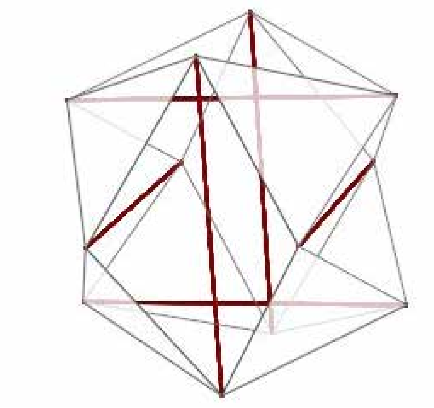


Fig.16.1, Icosahedron with solid triangular faces to illustrate the volume.

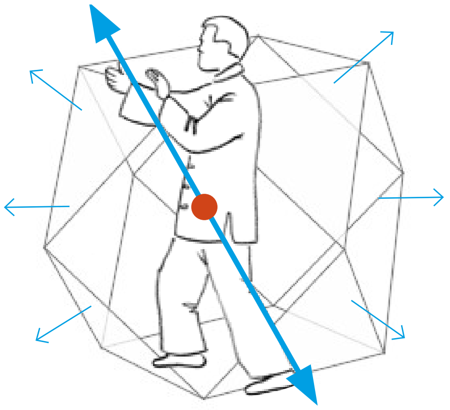


Fig.16.2, "Peng" (Ward Off posture) with expanded icosahedron in the background.

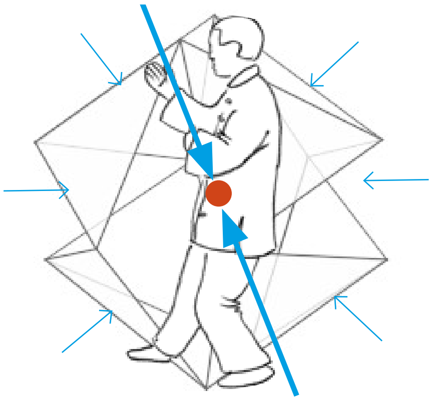


Fig.16.3, "Lu" (Roll Back posture) with compressed icosahedron in the background.

The tensegrity *icosahedron* also shows another interesting feature. When we expand or compress two struts, the tendons don't need to stretch much to accommodate the movement of the struts, as they are usually designed to be quite flexible. This results in a large visible change in the positions of the struts, while the tendons only undergo small changes in length. (Just compare the lengths of the blue and red arrows in Fig. 15.2 and Fig. 15.3.). The tendons primarily adjust their tension to maintain overall balance, rather than significantly elongating. As a result, the struts move much more (red arrows) than the tendons stretch, making the change in the distance between the struts much more noticeable. *V. G. Jáuregui*[15] describes this phenomenon in his masterwork as *elasticity multiplication*, highlighting the remarkable efficiency of TS-systems, where minimal elastic deformations lead to significant structural adjustments in the struts.

This characteristic provides a good explanation for the subtle internal shifts and weight redistributions in the body during a Taiji form. These shifts enable fluid, full-body movements with large, powerfully coordinated flows.

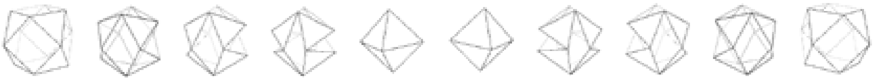


Fig.16.4, A TS-Icosahedron with solid faces and its corresponding transformation from expansion to compression and back to expansion.
More information about TS-Icosahedron as well as other types of tensegrities can be found in "Overview of tensegrity - I: Basic Structures" [21]

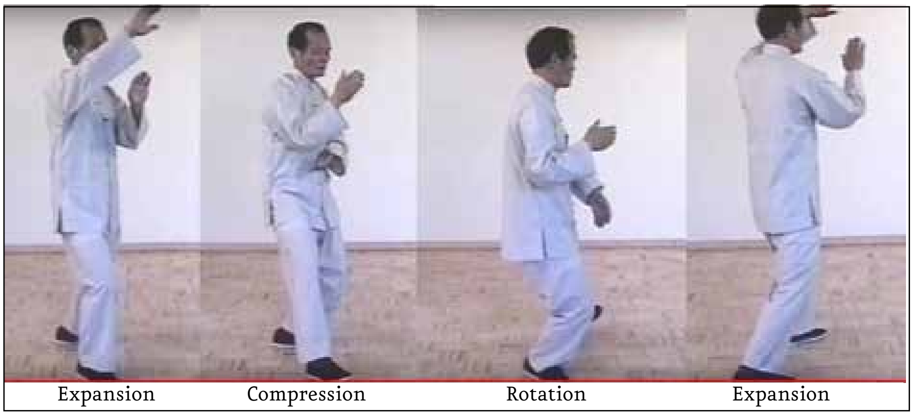


Fig.16.5, Ben Lo's "Fair Lady Weaves the Shuttle" demonstrates a good sequence with alternating "Peng" and "Lu," or "Expansion" and "Compression," while changing direction.

VL5 : Instagram
Check the effects of expanding or compressing individual elements.

类比 #4 身体直立：关于正确对齐的作用

Analogy | #4 Body Upright

About the Role of Correct Alignment

When I started learning Taiji, I was quite surprised at how often my posture and body alignment needed to be corrected by my teacher. The concept of an "upright body" sounds so simple. The rule for the correct posture and alignment of the head, torso, and hips corresponds to the same rules already explained in the first principle (#1 Relaxation) in the so-called "wuchi" stance. However, what's new is that you are simultaneously in motion or have just completed a movement and have taken on a different posture with your legs and arms. It seems, coordinating and realigning your body, especially in connection with movement, is not such an easy task.
But the associated benefits of 'proper alignment' are certainly clear:

- Even weight distribution to increase stability and protect the joints
- Better power or energy flow (Qi) by avoiding blockages in the body
- Increased efficiency of movement, as an upright and well-aligned body doesn't need to expend unnecessary energy to compensate for misalignments

That's why it's so important in Taiji to regularly check the alignment of the body to ensure that you're maintaining the correct posture.

For this principle, I will build a Tensegrity Mast. This means, for the first time, we will observe how several tensegrity modules are connected vertically. In advance, here is a brief description of *Tom Flemon*[16], a pioneer in the development of biotensegrity models. His work has played a crucial role in illustrating how tensegrity principles can be applied to the structure of the human body.

"Tensegrity masts have interesting properties. They can act like a spring, compressing under load but, unlike a spring, they can also self-extend. By applying circumferential forces to segments of the mast, e.g. squeezing or constricting the mast laterally, they narrow, becoming longer and stiffer, acting like a compression member and are able to bear significant loads. When the load is released, it becomes more flexible, bending and shortening."

In 1985, Tom Flemons recognized the similarity between tensegrity masts and our spine. He created models of tensegrity spines, which were sold to doctors and chiropractors. Although no one in biomechanics was exploring this connection, Dr. Stephen Levin, an orthopedic surgeon, was writing about it. The two met in the 1990s and collaborated for over a decade. Together, they developed numerous biotensegrity models, demonstrating that the human body could be understood without relying on traditional mechanical concepts like levers and fulcrums.[17]

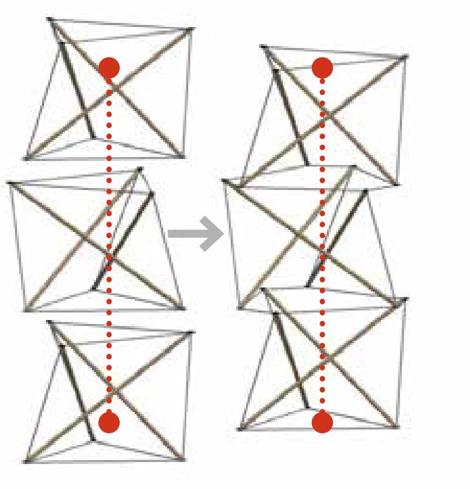


Fig.17.1,
Assembling a three-stage TS-mast with 3 "Simplex" models (left+right handed).

Fig.17.2,
Left and right handed 3-Struts TS model

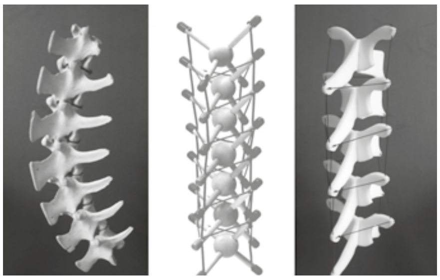


Fig.17.2, "Tetrahedral vertebral mast" demonstrating the spine; by Tom Flemons (intensiondesigns.ca)

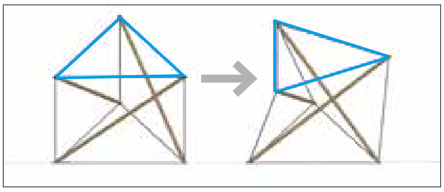


Fig.18.1 Isometric view of
prismatic model -> rotated top triangle (blue)

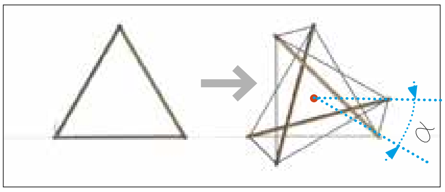


Fig.18.2 Top view
prismatic model -> rotation angle (blue)

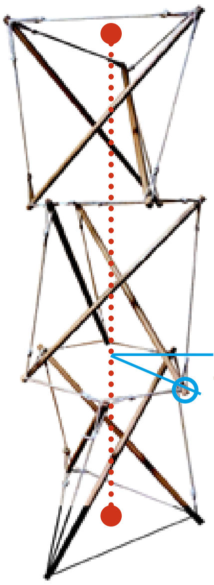


Fig.18.3
TS mast with three
models arranged on
top of each other.

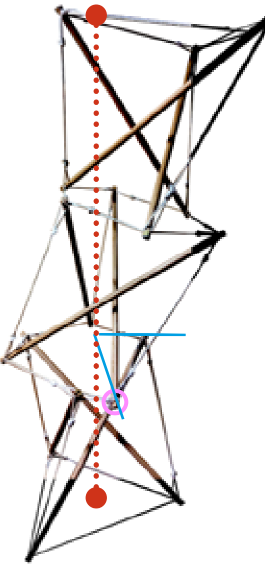


Fig.18.4
TS mast with
misaligned angle
due to one shifted
endpoint (purple)

While I used rubber bands in previous models to better examine the dynamics and flexible behavior, this composite model requires more stability. I achieve this simply by replacing the rubber bands with ropes. To further increase stiffness, one could also use tensioned steel cables, as seen in Kenneth Snelson's Needle Towers (page 7), which reach heights of up to 26.5 meters.

While the Needle Tower consists of multiple stacked three-strut elements, three elements are sufficient for this study.

But before proceeding, it is necessary to take a closer look at the classification and the associated stability criteria of those TS-elements. 3-Struts models are the simplest type of TS model and are also categorized as a prismatic tensegrity. T-prisms, or prismatic tensegrities, are generated from a straight prism in which the cables are either horizontal or vertical, and the struts are positioned diagonally between the vertices of the two different levels. If a relative rotation is introduced between the upper and lower polygons, a tensegrity prism is obtained. The rotation angle (α), or "twist angle", depends on the number of struts (n = number of edges of the polygon) and is given by the formula demonstrated by Roger S. Tobie[17]:
$\alpha = 90° - 180°/n$

Using this equation, we find $\alpha = 30°$ for a variant with 3 struts.
By alternating between left-handed and right-handed elements and ensuring that the strut endpoints do not touch within each layer, the tower takes on its well balanced vertikal shape.

If just one strut creates a misaligned rotation angle due to a displacement of one endpoint, the tower shifts from its vertical centerline (Fig.18.3 and Fig.18.4).
With further angle changes, the mast quickly reaches its structural limits, collapsing under the resulting misaligned forces (see videolink VL6).

This behaviour clearly demonstrated how critical the correct alignment of even a single component is for the overall stability of the whole structure.

In summary, not only does the proper relationship of tension and compression help stabilize a structure like the human body, but precise alignment also ensures that the correct tone is established between the forces, leading to a harmonious balance.

VL6 : Instagram
Have a look at a TS-mast
under external load and
misalignment.

类比 #5 美丽的女士手：关于姿势、结构与动作的和谐互联

Analogy | #5 Beautiful Ladies Hand

About the Harmonious Interconnection of Posture, Structure and Movement

This concept has challenged me for a long time, primarily because I wasn't sure how to approach it as a TS-principle. For quite some time, I viewed this principle from a purely technical perspective. Certainly, the positioning of the fingers relative to the palm, and the palm relative to the forearm, is important for managing a *Beautiful Ladies Hand Posture*. Yet, in this view, the focus seems to be on *proper alignment*, similar to the principle of *Body Upright*.

What stands out most, however, is the use of the adjective "*beautiful*" in this last Taiji principle. Perhaps the reference to "*beauty*" highlights, on a larger scale, the connection between posture, relaxation, and elegance. Taiji forms do more than make movements powerful and functional—they make them aesthetically pleasing. Taiji seeks harmony between body and mind, expressed through internal strength and external beauty. Thus, the movement is not only about external form but also about the internal coordination of body, mind, and energy.

The Taiji classic says:

> *"The mind (Yi) leads, the body follows."*

From this perspective, the last principle goes beyond *proper alignment* to suggest a deeper interconnection between all parts, aiming for a higher level of *beauty*.

Through this lens of "interconnection," I began to see a new way of comparing it to tensegrity.

So far, we have only looked at simpler TS-models, consisting of rods and strings. However, by altering number, materiality, and complexity, it is possible to create highly aesthetic models. Unfortunately, this requirement currently exceeds my capacity and skills.
Therefore, I will first discuss other realized models or projects before returning to my own smaller experiments.

To begin with, I would like to highlight the works of *David G. Emmerich* and *René Motro*. Both scholars made significant contributions to the study of form and structure, particularly regarding the functional properties of objects and systems and the interplay of their parts. Within the concept of "*structural morphology*," arrangements and interactions of structures are examined for stability, efficiency, and aesthetics. Their focus on the importance of structure in movement and design demonstrates how these principles enhance our understanding of fluidity and grace in natural and artistic forms.

But sometimes, it's not just the structure itself that matters, but also the choice of materials.
Since textiles are also suitable for being tensioned, they can serve as

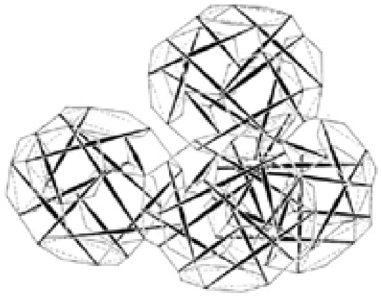


Fig.19.1 D.G. Emmerich's monograph Tensile and self-tensioning structures, showing a tensegrity structure composed of truncated octahedrons assembled by derotating the square faces forming octagons.

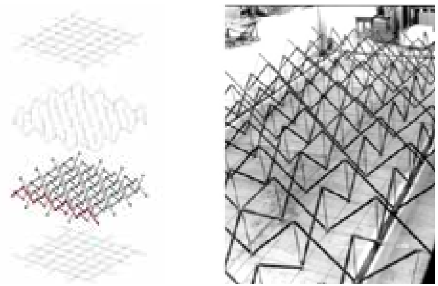


Fig.19.2 René Motro's patent of a bi-directional TS-grid, built in 2000, covering $82 m^2$ and weighing 900 kg. (René Motro. Tensegrity : from Art to Structural Engineering.)

Fig.19.3 The underwood pavilion as a case study to describe a design process that replaces traditional methodologies by digital methods, suggesting a new parametric design approach for lightweight structures and envelopes. (Gernot Riether and Andrew John Wit, 2015)

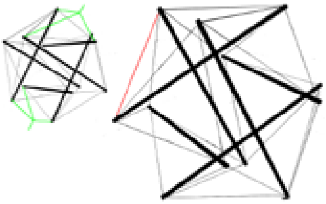


Fig.20.1, Tensile forces in a tendon (red) of the larger tensegrity can be transferred through a smaller tensegrity model. In this process, at the end of the larger tensegrity, one tendon is replaced by three tendons (green), thereby distributing the forces.

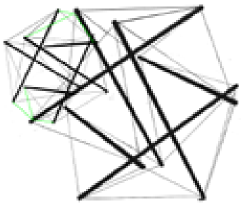


Fig.20.2, Such form is creating new equilibrium of forces in the linked system.

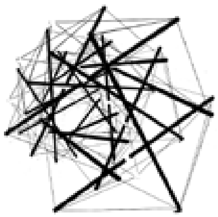


Fig.20.3, This type of fractal chaining can be scaled further in just one direction.

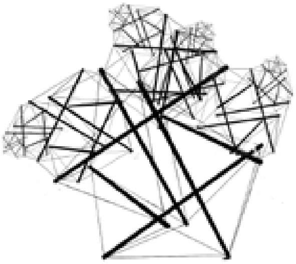


Fig.20.4, Finally, an example with multiple directions. A fascinating mix of order and complexity begins to form. Fractal patterns connect nature and mathematics in an aesthetic way.

an effective substitute for cables and ropes to handle tensile forces. An example of this is the "*Underwood Pavilion*," which was created by a group of architecture students from *Ball State University* with professors *Gernot Riether* and *Andrew Wit*. This tensegrity structure, interlinked with 56 lightweight, self-shading modules of elastane fabric, would not have been possible without design programs enabling parametric calculations, although it is fundamentally composed of assembled three-strut models.

Susan Lowell de Solórzano outlines for me another interesting possibility in her book *Everything Moves*[18]: the concept of a fractal chaining of TS-models. In this concept, a single TS element (strut or tendon) is replaced by an entire TS-model of similar design, but at a different scale level. In this way, a TS-model acts as a fractal seed shape, generating a network of interconnected structures that exhibit self-similarity across multiple scales.

Research on multifractal tensegrity systems is still at an early stage, with few results so far. Let us nonetheless imagine the body as a multifractal tensegrity system. Such structural hierarchies[20], inherent to tensegrity configurations, reduce weight, increase stability, optimize load-bearing capacity, dissipate harmful stresses, and connect all levels into a functional whole.
How could a shape based on this be described? And how might our senses respond to such connections?

At the moment, I can only vaguely imagine how movements or loads would respond in real models, such as the digital ones I have created, based on fractal systems (see Fig. 20.1-20.4). But one thing is already clear to me: when applied correctly, changes in this shape influence every part of the structure, always striving for a form that is both harmonious and, in a sense, natural.

To me, this perspective helps explain how our body, with the support of our fascia[22]—a dynamic, net-like continuum that pervades, subdivides, and connects every structure, much like the tendons in tensegrity models—coordinates mind and energy, constantly rebalancing itself to maintain grace and harmony.

Fig.20.5, Cheng Man-ch'ing practicing taiji in 1922 (source Wikipedia) showing a "Beautiful Lady's Hand" in a graceful and elegant way. His hand is expressing energy in a relaxed yet focused manner.

Fig. 21.1; Shadow play of Marit while practicing the Taiji form in Oslo.
Picture and photo montage by the author.

结论

Conclusion

The shadow of the Taiji person in my photo illustration represents an organic system in which everything flows, while the brick wall in the background, embodies a different, more rigid system. Of course, we cannot find any actual tensegrity models within our bodies or in a Taiji form. The concept serves only as an illustration of principles, behaviors, and the geometric representation of force distribution within systems.

Tensegrity, as a structural principle, has been less successful as an architectural concept throughout its history. Instead, it has been more effective as a model for explaining natural, and even cosmological, phenomena. So far, tensegrity seems to be the best model for illustrating these nature-like phenomena. Just as biological organisms always strive to operate with maximum efficiency, self-assembling systems like tensegrity do the same.

And yet, knowledge of tensegrity appears to be scarcely present in our society. Instead, we continue to be influenced by hierarchical and linear principles like the brick wall.
How influenced we are by our rigid, built environment is evident in our initial amazement about the discontinuous nature of tensegrity. These seemingly light and weightless models often appear so incredible because they barely fit into our usual understanding of human-made constructions. Yet, they simply reflect a natural principle.

A tensegrity structure shares far more similarities with all biological bodies and plants than other models. A simple blade of grass, for example, reaches an incredibly tall height despite its thin cross-section; it withstands external forces like wind and rain and even manages to adapt and straighten itself when pressed down. These exact characteristics can be illustrated using a tensegrity model. And yet, this simple ability of a blade of grass puzzled scientists for a long time.

But it doesn't take scientific descriptions or calculations to understand such behaviour. Humans have always studied nature, observed it, replicate and tried to adapt to it. With varying results and outcomes throughout human history, as we know. But it's safe to say that the better one could adapt, the more harmonious the outcome. The development of Taiji in relation to human movement appears for me in the same way. Even the supposed origin story of Taiji speaks volumes, in the legend of the crane and the snake:

"Zhang Sanfeng, while in deep meditation, witnessed a fierce yet graceful battle between a crane and a snake in the wilderness. The crane, with its powerful wings and swift movements, would try to peck at the snake from above. The snake, in response, used subtle and fluid motions to evade the crane's attacks, coiling and uncoiling with precision and agility. Neither creature was able to overpower the other, demonstrating an elegant balance of attack and defense."

From this interaction, Zhang Sanfeng saw the embodiment of yin and yang. He realized these principles could be applied to martial arts, leading to a new system that balanced hard and soft techniques, strength and flexibility.

Through centuries of passing down this Taiji wisdom, there has never been a need for a tensegrity model to understand it—nor will there ever be.

However, I am personally very grateful for this structural journey, which has clarified and organized my thoughts. It has also helped me connect my Taiji practice more clearly with the laws of nature and the harmony they embody. Simple principles that carry the essence of deep wisdom within them.

In this regard, I feel only reverence and deep gratitude for the opportunity to be part of this tradition. And if I am allowed to carry it forward, I am confident that drawing a connection with tensegrity will remain true to its essence.

笔记

Notes

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