THE DEVELOPMENT OF INFLATABLE MATERIALS

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INTRODUCTION

When most people think about inflatable products, they are put in mind of blow-up toys, swimming rings, or party balloons, all of which are insignificant or novelty items. And indeed, the market is inundated with such cheap, shoddy, and frivolous inflatable products. Since many inflatable products are seemingly produced without much consideration for their design, few people are willing to spend their time sifting through it all, and most don't have the inclination, since they are unaware that there are actually some very important inflatable products available too.

During the research process, I found a series of cases which demonstrate the vital role that inflatable objects have played in our social development. For example, the inflatable sheepskin raft allowed the economies on both sides of the Yellow River to thrive; the hot air balloon took humankind to the skies for the first time; pneumatic tires changed the landscape of cities forever; inflatable decoys were used in World War II, and helped the Allied forces defeat the Nazis; and some of the most environmentally friendly architecture was built with air-filled membranes. These applications of inflatable technology have variously protected us from harsh environments, aided us in war, saved us from urban chaos, and inevitability changed our lifestyles.

All of this has been driven by the development of inflatable materials. Throughout history, the first materials used in the creation of inflatable products were animal organs, however, with the development of materials science, rubber, and later PVC took their place and played a significant role in the design history of inflatable materials. However, due to environmental and sustainability considerations, rubber and PVC are being gradually replaced by new environmentally friendly materials, and designers are being challenged to use materials which used to be considered unsuitable for inflatable products.

Every time inflatable materials have changed, or new ones have been developed, this occurred within a unique social context. This is what fascinated me, and so I wanted to examine inflatable objects from the perspective of the materials used in their manufacture. In this dissertation, I will try to outline the history of the materials used in inflatable objects, and what designers intended to do with these (then) newly emerging materials.

Figure. 1: Inflating the Pig Bladder

PIG BLADDERS AND SHEEPSKIN

Long before rubber or plastic materials were invented, animal organs were the perfect materials from which our ancestors could make inflatable objects. Due to the fact that they were airtight, highly stretchable, and a renewable resource, animal organs were used in entertainment, business, and transportation etc. The influence of many of these early applications still endures in modern products, and they significantly changed the way we look at the world.

The ancient soccer balls are a good example of how our ancestors utilized inflated animal organs for entertainment. From a couple of centuries BC to about 200 AD, the Chinese used stuffed spherical stuffed balls made from animal skins in a game called 'Tsu Chu', in which players had to pass them through a net stretched between two poles. The ancient Greeks, Romans, and even the Egyptians are also known to have enjoyed similar games that involved kicking a stuffed animal-skin ball.[1]

In medieval Europe, a new way of making balls for entertainment was developed. Due to the popularity of soccer, light, durable elastic balls were in high demand. The Italians began using inflated pig bladders as balls in the 17th century, and they became the most common material used for soccer balls in Europe shortly thereafter. Later, due to their lack of shape retention (which made them harder to play with), and the ease with which they ruptured, it became common practice to cover the pig bladders with leather. [2] With these new leather covers, soccer balls became rounder and lasted longer. Despite the fact that the modern soccer ball has experienced several evolutions in terms of the materials used and the manufacturing processes, the basic structure of the modern soccer ball was determined at that time.

Besides their use in entertainment, inflated objects also proved their value in commerce and transportation. As mentioned previously, the people of ancient China who lived in Yellow River valley invented a watercraft which was made of sheepskin. The entire skin of a sheep was peeled and then inflated, whereupon many would be trussed together into rafts.[3] The reason inflated sheepskin rafts emerged in this area was that unlike other rivers, the Yellow River runs all the way down to Loess Plateau from the Tibetan Plateau, during which time, the amount of sediment being carried increases rapidly, causing strong currents, narrow waterways, and shallow riverbeds. Typical watercraft which are made of wood or

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[1] http://soccer.epicsports.com/soccer-ball-history.html (accessed September 2016)

[2] http://www.soccergearhq.com/who-invented-the-soccer-ball/ (accessed September 2016)

[3] http://baike.baidu.com/view/945877.htm (accessed September 2016)

Figure. 2: Sheepskin Raft

bamboo were therefore too heavy for this environment, besides which, building wharfs in such conditions was nigh-impossible. Therefore, inflated sheepskin rafts took their place.

Making these sheepskin rafts required highly skilled craftsmen. The peeling process would normally begin with the creation of incisions around the sheep's neck, after which the entirety of the animal's skin would be slowly peeled off in a single continuous undamaged piece. After removing the hair and inflating the skin, the craftsmen would then fill the inflated leather with Tung oil, salt, and water. The limbs would then be tied up and the skin exposed to the sunlight for one month. In order to create a raft, the craftsmen would then bind many of these inflated sheep skins together in compact rows, which would be enclosed within an ash tree frame. The rafts could also be easily disassembled, meaning traders could load their goods and sail downstream with the current, then, upon reaching their destination, they could unload their goods, deflate and disassemble the raft, and travel back upstream via land relatively unencumbered. The endurance and load-bearing capacity of these rafts are equally striking. It has been recorded that the largest sheepskin rafts could sail up to 300 miles, and were so large that people could even build tents and live on them.With developments in transportation technologies, the sheepskin raft gradually became obsolete for shipping. But their use is becoming popularized once again due to the demands of tourism.

As a light-weight and flexible form of water transportation, sheepskin rafts helped ancient Chinese people to transport cargo and passengers between each side of the Yellow River, and they are once again in use today thanks to tourism. These rafts have therefore played a significant role in the history and economy of China. I credit this to the properties of the material itself, which is entirely recyclable and sustainable. The use of sheepskin not only helped our ancestors to overcome the extreme challenges of their environment, but also minimized the damage done to nature when compared with the use of wood or metal materials.

Both pig bladder soccer balls and sheepskin rafts show how ancient people utilized inflatable technologies prior to the industrial revolution. Since that time, the emergence of new chemical materials has totally changed the way inflatable products look, and mass production has made them more accessible and affordable, but these products now have a significant environmental cost, and are gradually ruining our planet. So, while people nowadays may feel that these ancient objects are primitive, absurd and even disgusting, compared with modern inflatable products, they are virtuous and elegant. We often find answers to our questions by looking to history, and these ancient technologies could teach us a valuable lesson.

Figure. 3: First Hot Air Balloon, Montgolfier Brothers, 1783

LINEN AND PAPER

Since a variety of materials and technologies were invented or developed during the first industrial revolution, inflatable technologies progressed significantly during this time. A relatively new material discovered in the last century gave pioneers new ways to solve many problems which had previously been considered insurmountable.

Flying was long a dream of humankind. Most people know that the airplane was invented by Wright brothers and brought humankind to the sky, but hot-air balloons had already done so two hundred years earlier.

The first hot-air balloon was invented by the Montgolfier brothers in the 1780's in France. They ran a paper producing business in Annonay and had a great interest in mechanical engineering, as well as a dream to fly one day. It is said that they were inspired by a t-shirt which was hung above a stove to dry and became inflated, it was then that they realized that hot air is lighter than cool air, and that this principle could be used to achieve flight. Soon after, they performed an experiment in which they used a paper bag to gather hot air together, and were able to make it fly. The first successful public demonstration of their hot-air balloon was held on 4th June 1783, in their hometown of Annonay.

The materials used in this balloon were linen and paper, and the inventors had fashioned them into a spherical shape, approximately 11 meters in diameter. It climbed to an altitude of over 100 meters, and travelled a distance of almost two kilometres.[4] This event was considered to be the birth of aerostatics. This monster construct first invoked fear among people, but their fear was soon transformed into curiosity, and due to the invention of illustrated engravings, a newly emerging mass media quickly communicated the news to the whole of France.

Montgolfier brothers' second balloon test was launch on 19th September 1783, an event which was witnessed by over 12,0000 spectators. This would also be the first time that a hot-air balloon carried live passengers which included a sheep, a duck, and a rooster. The sheep was believed to have a reasonable approximation of human physiology. The duck was expected to be unharmed by being lifted aloft. It was included as a control for effects created by the aircraft rather than the altitude. The rooster was included as a further control as it was a bird that did not fly at high altitudes.

This demonstration was held at the royal palace in Versailles, before King Louis XVI of France and Queen Marie Antoinette. The flight lasted approximately eight minutes, during which time the balloon covered 3 kilometers, and reached an

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[4] Sean Topham, *Blowup: Inflatable art, architecture and design* (Munich; Prestel, 2002), p.17.

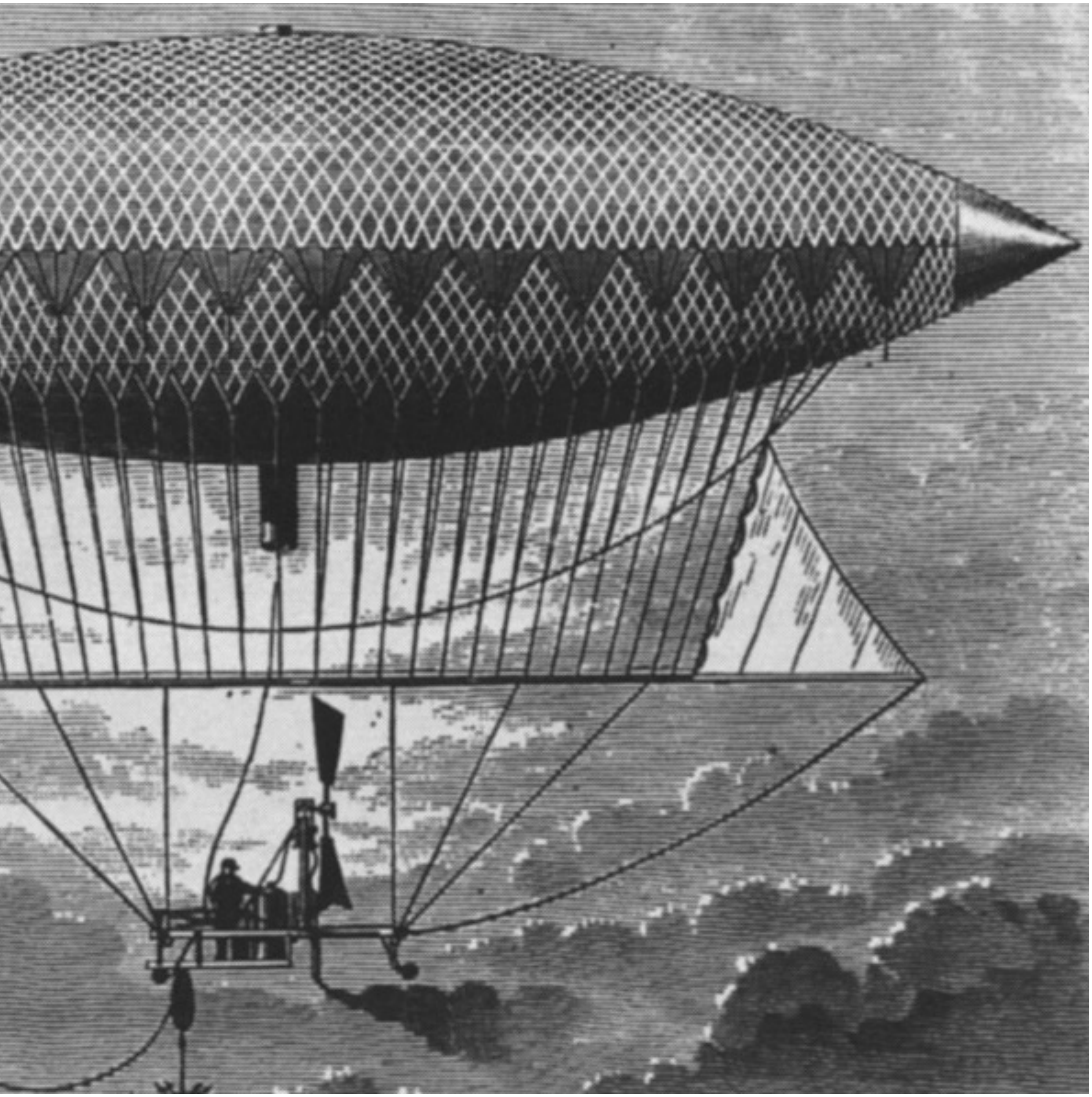

Figure. 4: Dirigible Balloon, Henri Giffard, 1852

altitude of approximately 460 metres. The craft landed safely after the flight. Three months later, the first manned hydrogen balloon was launched by another balloon pioneer, Jacques- Alexandre Charles. It travelled much longer and farther than that of the Montgolfier brothers, and was equipped with many advanced meteorological devices such as barometers to record the atmospheric conditions.

The success of the balloons of the Montgolfier brothers and Alexandre Charles soon attracted the attention of the French military, who believed the invention could be used as a monitoring platform on the battlefield. It proved its value in battle when France defeated the Austrians at Fleurus. Despite the fact that the balloon was considered to have helped on the battlefield, it still had a lot of room for improvement, as it lacked any reliable system of control once airborne, and could not travel against the wind. Henri Giffard made the first dirigible balloon in France in 1852. He applied a steam engine system to control the airship, and designed the exhaust to enter the inner section of the balloon to create lift force, though in doing so it also risked causing explosions with sparks. His airship voyaged over 27 kilometers from Paris to Elancourt. Although the strong wind prevented him from returning via the same route, the ability to turn and cycle the airship proved it was controllable.[5] The fully controllable airship was produced by the Lebaudy brothers until 1903, and was equipped with advanced navigation systems and a powered engine which allowed it to fly against the wind. The military's designs on these devices also changed accordingly, and instead of a monitoring platform, they saw a potentially powerful weapon.

Throughout history, the development and use of new materials and technologies has completely revolutionized people's understandings of inflatable objects. In the case of the linen and paper balloon, people first feared it was a demon flying above their heads; later, after the successful manned flight of the hydrogen balloon, the military felt it could be used as monitoring platform; then with the development of the steam engine powered airship, its potential to be used as a new kind of weapon was recognized. It was not only people's understanding that was revolutionized during this time, but their social awareness too. During this period, most land in France was owned by the French authorities, but none had laid claim to the sky. The success of the hot-air balloon made people aware that it represented a way to escape the control of the ruling class, and so it came to represent the possibility of a free future. As a consequence, the development of the balloon accelerated the French revolution, and pushed the whole nation towards democracy, influencing the course of the European revolution.

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[5] Sean Topham, *Blowup: Inflatable art, architecture and design* (Munich; Prestel, 2002), p.29.

Figure. 5: Leather Covered Soccer Ball, Richard Lindon, 1849

RUBBER AND PVC

With the development of new materials, designers were provided with alternative ways of making inflatable objects. Plastic and rubber are the most commonly used materials in inflatable objects, and their application for this purpose changed the way people live.

As mentioned previously, pig bladder balls were at one time the most widely used balls on the soccer field. However, these balls were not perfectly spherical, and were easily punctured, features which restricted the development of soccer. Richard Lindon was a leather worker whose wife died of a lung infection (possibly caused by her work inflating pig bladder), and he decided to find another way of making soccer balls. He recognized that India rubber might be a suitable option, though this material was too firm to inflate by mouth. But he found a solution to this problem; taking medical syringes as his inspiration, he fashioned a copper pump to inflate the rubber balls. As a leather worker, he also found a way to make the cover; he used six pieces of leather, sewing them together and fastening the ends together with a button.[6]

Around the same time, Charles Goodyear, the American chemist and engineer, had a similar interest in Indian rubber. Although the material was already in use in certain products like soccer balls and solid tires, they had undesirable properties such as stickiness and perishability, and their lack of elasticity restricted the material's further application. After being introduced by a friend who was the manager of a rubber company, He was able to secure several investors for his experiments.

His first experiment involved gum rubber, which sold for a reasonable price at the time, and after several tests, he discovered that infusing the molten rubber with magnesia enhanced its physical properties. The result was a beautiful white compound which was less sticky than the base material. He considered this to be a notable progression, and believed he had found the secret to improving its use. The first product he attempted to make was a pair of shoes, and he used his house as a laboratory to continues his explorations. He would later add more ingredients to his compound, dissolving the gum rubber, lampblack, and magnesia into turpentine to create a new compound. However, even when treated in this way, the end product was still sticky. The investors gradually lost their patience with his experiments, and ceased funding them.[7]

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[6] http://richardlindon.co.uk/ (accessed September 2016)

[7] http://connecticuthistory.org/charles-goodyear-and-the-vulcanization-of-rubber/ (accessed September 2016)

Goodyear, however, would not stop in his explorations, and continued the experiments with the help of his friend who was a druggist. This time, he tried to mix the rubber and magnesia and then put the mixture into boiling quicklime water. The result was quite surprising - the compound seemed to have lost its stickiness. The news soon spread all over the world, and he received international acclaim. He seemed very close to triumph, but one day he accidentally dropped weak acid on the synthetic rubber, which neutralized the alkali and the rubber became soft once again. He realized that his experiment was another failure, and began to look for a new formula. After year after year of experimentation the toxins in the lab began to notably affect his health, but he finally found what he was looking for. He discovered that when vulcanized rubber was dipped in nitric acid, the surface becomes cured, which protects the rubber from other acids. This time, he had finally succeeded, and would even receive a letter of appreciation from the then US president Andrew Jackson.

Mr. Goodyear may never have been realized how much his invention would change the world, creating a new epoch in which vulcanized rubber would be used in a wide variety of applications due to its elasticity, plasticity, thermostability, and anti-aging. Today, rubber can be found in many products such as household items, clothes, and industrial machinery, but the most notable use of rubber is in inflatable tires.

However, long after the invention of vulcanized rubber the old, solid rubber tires were still used on cars. The horrible noise and turbulent travel experience that they provided constituted a barrier to car travel becoming a desirable method of transportation. Later, the British inventor Dunlop would improve the bicycle tire, patenting his new inflatable tire. Then, French inventor Michelin Brothers invented the radial tire which was more durable and reliable, and so this tire was soon widely used in European and especially America cars.

The invention of pneumatic tires made travel by car significantly more comfortable, improved fuel efficiency and meant that cars required fewer repairs. Their invention enormously stimulated the US car industry, and fueled the boom in car production in the 1920s. More significantly, due to the widespread adoption of inflatable tires, the efficiency of society as a whole was also enhanced, contributing to the booming of the American economy during World War I. This revolution in tire technologies not only changed city landscapes, and helped create our modern way of living, but also shifted the balance of military power. At that time, the Unites states controlled several rubber producing regions, including Brazil and Southeast Asia, and many pneumatic technologies related to rubber were used in the building of military vehicles, warships, and dirigibles.

Rubber devices were also built and used in Europe during World War II, but in a completely different way. Many inflatable tanks, aircraft, bridge were built as decoys

Figure. 6: Decoy Inflatable Tank

to in an attempt to keep vital targets safe from harm and to cause the enemy to waste their valuable ammunition. These inflatable decoys played a pivotal role in the liberation of France from the Nazis, weakening the German armed forces.

Air Commodore R. Collinshaw was the first to conceive of this idea. After examining the merits and drawbacks of the use of inflatable rubber for this purpose, he outlined some essential criteria for the decoys: *"A: They must be full size and normally camouflaged. B: they must be mobile and capable of being reestablished at fresh site within a few hours, and C: The dummy aircraft ought not to require much military transport to move them and very little labor to dismantle or erect them at the fresh site…".*[8] He suggested that the inflatable aircraft could be produced in a similar fashion to how inflatable animal skins were, except the aircraft decoys would have to be full-scale. He also posited that the inflatable aircraft could be rolled up when not in use, making them easily transported via small containers, and stipulated that they must be deployable on short notice.

Nevertheless, his superiors disagreed with his assessment, arguing that the aircraft would be too fragile if the rubber was made thin, and too heavy if the rubber was made sufficiently thick. Besides which, their experiences of World War I told them that decoys were ineffective at attracting the enemy's attention unless a lot of time and effort was invested into making them convincing.

However, later research and development into the use of pneumatic apparatus showed that it was possible to make full-scale inflatable models. The skin of these models was made from rubber-dipped fabric, which was light, durable, and airtight. The next step was to make them more realistic, and two ways for achieving this were proposed. The first was to create a frame with inflatable beams and cover it with fabric. The alternative was to make every component at a 1:1 scale and then assemble them with internal connections. The second methods proved to be more realistic-looking and efficient. The decoys were also coated in metallic paint, which created a reflective surface that made them seem almost real, meaning German pilots were unable to distinguish between decoys and the real thing when in flight.[9]

These dummy pneumatic constructs had proven their ability to deceive the enemy, and would play a vital role later in the war during the invasion of Normandy, which is considered to be the turning point of World War II

The demand for rubber was huge during World War II. The Sherman tank for example contained half a ton of rubber, and some warships had over 2,000 rubber components. Every centimeter of wire was also covered with rubber and was used

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[8] Sean Topham, *Blowup: Inflatable art, architecture and design* (Munich; Prestel, 2002), p.34.

[9] Sean Topham, *Blowup: Inflatable art, architecture and design* (Munich; Prestel, 2002), p.41.

all across the country. When the Japanese attacked Pearl Harbor, they simultaneously launched strikes in Malaysia and the Dutch East Indies, taking over almost 90% percent of the world's rubber production, plunging the United States into a crisis.[10] Therefore, finding an alternative material became a most urgent task for scientists.

German scientist Friedrich Heinrich August Klatte was the first to patent PVC, creating it by polymerizing vinyl chloride with sunlight. However, US scientist Waldo Semon discovered a way to make the material more processable whilst working at BFGoodrich. The discovery was made while he was trying to heat a mixture of dissolved polyvinyl chloride powder, and inadvertently created a jelly-like material. This material was called plasticized PVC.[11] It was cheaper than rubber and could be manufactured to be harder or softer by adding plasticizers. It was also highly processable and could be made into solid or film forms. As a consequence, plasticized PVC soon became a popular substitute for rubber and saw use in many fields. The world was in a frenzy about this new material.

The material first saw use in the field of architecture. In 1942, in California architect Wallace Neff used a huge PVC balloon to form a cast for the construction of a cement house, this was the first time pneumatic technology was used in this field. The PVC balloon was fixed to the ground, and then inflated. Cement was then sprayed onto the surface of the inflated balloon and left to dry, once dry, a rebar structure was built on top and it was sprayed with another layer of cement. After the building had dried, the balloon could be deflated for use in future construction.[12] Despite the fact that this method of building was cheap and efficient, it was never popularized, and was soon abandoned.

Several years later, Walter Bird made the first air-supported shelter. The US military needed a shelter to protect their fragile and sensitive radar devices from the elements, the shelter needed to be easily transported to different sites on a regular basis, and couldn't be too thick lest it interfere with the radar signals. Walter Bird judged that an inflatable structure would do the job, and so he applied his knowledge of materials and engineering to create and test several prototypes before finally creating a 16.5m tall fully air-supported dome.

The trend of creating inflatable structures soon spread throughout the world, and Walter's principle was further developed by many other architects including Frei Otto and Buckminster Fuller. The most ambitious piece of inflatable architecture

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[10] http://www.iisrp.com/WebPolymers/00Rubber_Intro.pdf (accessed September 2016)

[11] http://www.nytimes.com/1999/05/28/business/waldo-semon-dies-at-100-chemist-who-made-vinyl.html?_r=0 (accessed September 2016)

[12] Jacobo Krauel, *Inflatable Art, Architecture & Design* (London; Links International, 2014), p.26.

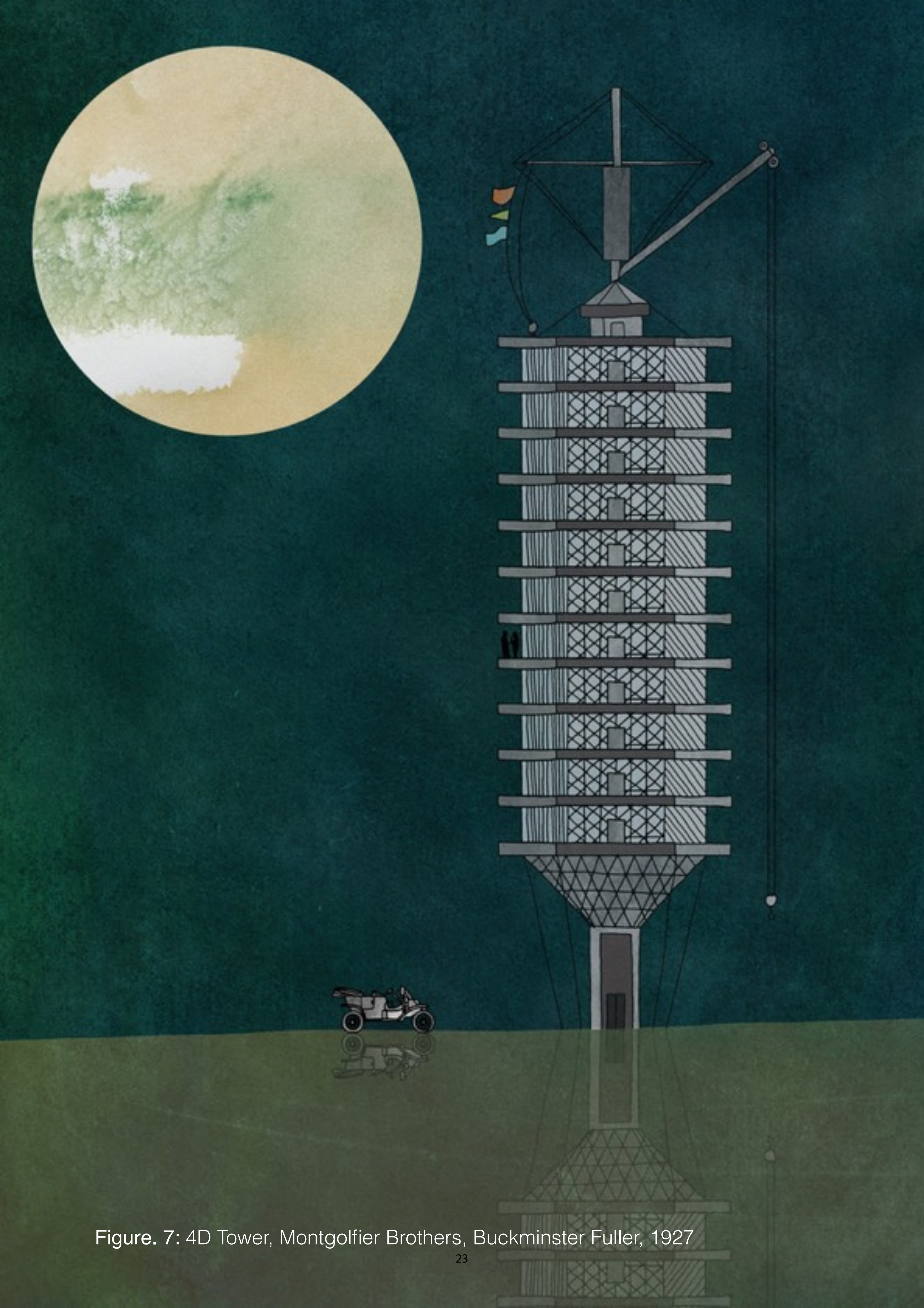

Figure. 7: 4D Tower, Montgolfier Brothers, Buckminster Fuller, 1927

was conceived by Fuller, who proposed to build a 12-floor building made from plastic which could be transported by air. A central mast would serve as the backbone of the building and the supply hub for services such as water or electricity. The rest of the building was to be made of plastic, including the doors, floors, and windows. He divided the whole building into many sealed airtight units which he believed would keep out dust, and a central air circulation system would provide fresh air to each unit. It was thought that the building would be much lighter and cleaner than conventional buildings and could be transported by air and deployed with less effort. Although this idea was never put into practice, the idea of having a central mast has been used in many modern buildings. [13]

As a result of Fuller's designs, the idea of 'pneumatic living' became increasing popular in the 1960s, and other architects and product designers began to experiment with creating inflatable furniture. The first inflatable chair was designed by Jonathan De Pas, Donato D'Urbino, Paolo Lomazzi, and Carla Scolari, all of whom grew up in Milan and trained as architects. The chair was manufactured by Zanotta in 1968. Zanotta was the most avant-garde furniture company at that time and the first to dare to use this new material and technology in their furniture. This chair was made from PVC film and used ultrasonic welding to connect the various pieces of PVC film together.[14] The furniture could be produced in transparent or translucent in various colors, and could be used both inside and outside, and even in swimming pools.

The chair was a huge commercial success in the 1960s and the design was applied to other, similar furniture. It also inspired another designer, Quasar Khanh to devote his entire career to developing inflatable furniture. However, the chair is considered more a fashionable decoration nowadays than a functional piece of furniture, and its success is now regarded as a response to the fact that PVC was fashionable in the 1960s. The short life span of the furniture, its bouncy quality, and colorful transparent materials taken together became an echo of the pop movement in the 1960s.

Therefore, before long, this kind of furniture was abandoned by most people and hence the market. By giving little consideration to durability, designers had created an unusual lifestyle which was seen as odd, and inflatable furniture was regarded as inane, or bought as an ironic piece. Furthermore, the oil crisis of the 1970s caused the price of PVC to quadruple, resulting in a massive decline in production

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[13] https://adlibitumdreams.wordpress.com/2012/05/28/richard-buckminster-fuller-4d-tower/ (accessed September 2016)

[14] *Blow,* V&A Museum, Furniture, room 133, case BY2, shelf CASE, box WALL

Figure. 8: Silver Cloud, Andy Warhol, 1966

Figure. 9: Dreamspace, Maurice Agis, 2006

of PVC products, and the shortage of recourses and the concern of environment made the disposal product seems irresponsible. [15]

In the field of art, artists also began to see the potential of using PVC. In the late 1950s, the economic structure of the USA was transforming from a primarily industrial sector to a service sector. Hence, economic growth no longer relied upon producing physical products, but on more intangible assets. This change was reflected in the easel painting of the era, which changed from Impressionism to Abstract Expressionism. The sculptures, however, did not change much, and so these artists were looking for a new way to make their works relevant in this new social context. The potential applications of inflatable PVC attracted the attentions of certain artists, its ephemeral and empty qualities making it an ideal material for contemporary sculptures.

In the exhibition of Air Art which was hosted by the Art Council of Philadelphia. Andy Warhol launched his work Silver Cloud. He filled silver Mylar pillows with helium and oxygen and let them float throughout the gallery, meaning viewers could interact with the pieces. Before exhibiting them in his gallery, he made some in his studio and released them from his window, creating publicity for his work, and allowing everyone in the street to see his work without needing to attend the gallery.[16] This work completely changed the face of sculptures, which had always been associated with heavy, static, and permanent qualities; and it also liberated sculptures from the gallery.

Instead of merely interacting with space, inflatable sculptures can also become the space itself. Maurice Agis is an artist who focused on experimenting with large inflatable enclosures. He first experimented with creating some inflatable cells in museums, but felt that the museum space was restricting his art, and so decided to place his work outside instead. His most iconic project was The Dreamspace, and consisted of 88 cells, each of which was unique and measured 5 meters high. The colors chosen for these cells were influenced by Piet Mondrian - the artist wanted to use bright and cheerful colors to let spectators escape the chaos of the outside world whilst walking within the art installation. The entire work was made of PVC, and the light and collapsible qualities of the material aided in the piece's transportation, making the work possible. In this way, art was brought out of the gallery and into public places.

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[15] Sean Topham, *Blowup: Inflatable art, architecture and design* (Munich; Prestel, 2002), p.141.

[16] http://www.warhol.org/education/resourceslessons/Billy-Kluver-and-Andy-Warhol--Silver-Clouds/ (accessed September 2016)

Figure. 10: Eden Project, 2001

ETFE AND METAL

Although PVC has proven to be the most efficient and affordable material for use in pneumatic objects, it has drawn criticism due to the environmental impacts of its use. As we know, PVC is made from oil, and the use and production of PCV has accelerated the depletion of the world's oil reserves. Additionally, plasticizers have to be added during the manufacturing process in order to enhance the physical properties of the PVC, but the abuse of these plasticizers can cause many diseases such as heart disease, diabetes, and cancer. The recycling process is also wrought with difficulties; burning PVC generate dioxin which is an extremely poisonous gas. Burying PVC is not a feasible option either, since it takes thousands of years to degrade. The fact that PVC is so widely used, and widely considered a disposable material amplifies these issues, and so many regions and large organizations have begun to limit or abandon the use of this material. Therefore, material scientist and designers are working together to find alternative inflatable materials. Meanwhile, the social context of their use has also changed a lot, and so new uses for inflatable objects have also become popularized.

ETFE membrane is new light-weight material used in the facades of buildings. Normal ETFE panels consists of three layers of ETFE membrane fixed within a metal frame, and after inflation, these panels can be used as a basic module for building facades. This material is recyclable, durable and provides brilliant heat-proofing. When compared to ordinary glass facades, the same area of ETFE panels make up only one percent of their weight and provide improved strength. Furthermore, because of their modular nature, if one of the membranes is damaged, it can easily be replaced with a new one; and if newer materials are developed, the design can also be updated to make use of them.[17]

The Eden Project is the largest botanical garden made from inflatable EFTE membranes in the world. The garden consists of eight three-quarter shepherd domes, and each dome is comprised of hundreds of inflated hexagonal ETFE panels. The shape of these panels was inspired by honeycombs, which use the minimum materials to achieve a high strength structure. This building provides an optimal environment for plants, as the transparent inflatable cushion it creates can store heat and warm the interior of the dome. It also allows more sunlight to enter than in conventional designs, which besides providing optimum conditions for photosynthesis, saves on energy. The income from this project is also considerable. Since its opening in 2011, the botanical garden has become a popular tourist

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[17] Sean Topham, *Blowup: Inflatable art, architecture and design* (Munich; Prestel, 2002), p.141.

Figure. 11: Concrete Canvas, William Crawford and Peter Brewin

attraction and brought in nearly 150 million pounds of revenue for the local economy.[18]

These ETFE membranes have also been used to build stadiums. The most well-known of which is the Water Cube, the Chinese national aquatics centre for the 2008 Beijing Olympics. The pattern on the exterior walls was inspired by the bubbles in soap, and so the designer covered the exterior with 4,000 ETFE cushions, arranging them in this pattern. This ETFE pillow also served as the interior lighting controller; a layer of translucent film was placed inside the ETFE cushions and can be adjusted to adapt to various external light conditions, thus reducing the need for artificial lighting.[19] As with the Eden Project, the ETFE membranes were also able to balance the indoor and outdoor temperatures, and hence reduced the energy consuming. In addition, the air cored structure combined with the use of transparent materials meant that lighting effects could be incorporated into the design. LED lights were placed in each of the air bubbles, allowing the 'skin' of the building to interact with sounds or graphics, making it seem more alive and attractive.

As mentioned in the previous chapter, the use of inflatable buildings was never shown to be practicable for the construction of large scale architectural projects, but its use in smaller buildings may be more feasible. Concrete Canvas is an inflatable material which was recently invented by a UK company: *'Concrete Canvas is flexible, concrete-impregnated fabric that hardens when hydrated to form a thin, durable, waterproof and fire resistant concrete layer.'*[20]

Concrete Canvas is light and collapsible, allowing it to be rolled up and transported to the construction site with minimal effort. Compared with conventional concrete buildings, Concrete Canvas uses less concrete for the same volume houses. The company has already tried to use this material to build permanent shelters. It was reported that a 44 m^2 concrete shelter was built by a two-man team within just one hour. It is quicker and cheaper than conventional building, whilst being more durable and long-lasting than tents. It is a perfect product for tough environments such as earthquake-prone areas, mining sites, or battlefields etc.

'Forget flat-pack: the future of furniture is inflatable steel.' [21]These were the words of Oskar Zieta, a Polish designer who has used a newly developed technology to

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[18] http://www.edenproject.com/eden-story/behind-the-scenes/architecture-at-eden (accessed September 2016)

[19] Wang Shuangjun, *Water Cube ETFE pneumatic membrane structure technology* (China; Chemical Industry Press, February 2010), p.31.

[20] http://www.concretecanvas.com/ (accessed September 2016)

[21] http://www.wired.co.uk/article/steel-goes-superlight (accessed September 2016)

Figure. 12: Plopp Stool, Oskar Zieta

make various inflatable metal products, ranging from furniture and household products, to architectural constructions. The products look like toys at first glance, and appear to be soft and fragile, but when you begin to handle it, you soon realize that it is load-bearing and durable. These pieces are challenging the common conception that inflatable objects are soft and flexible.

The metal inflating technology FIDU (Free Inner Pressure Deformation) was invented by Zieta, and the production process is quite simple. It involves using a laser to cut out the desired shapes from a metal sheet, and then weld the edges together and inflate them until a solid three-dimensional shape is formed.[22] Working with FIDU technology is similar to carving clay, the internal pressure causes the metal to change shape on its own and exhibits the natural results of this distortion. *'We can predict how the deformed object will look by the geometry of the cut, the pressure level, and the anisotropy [innate directional properties] of the material,'* [23] the designer explains. So, unlike CNC manufactured products, FIDU manufactured products are all unique but still mass producible.

As the materials used in construction and manufacturing are becoming more unconventional, the applications of inflatable devices have also become more distinctive. A company called SQUEASE developed an inflatable vest which, when inflated, gives the wearer the simulated feeling of being hugged. It is hoped that this could help people to release tensions, especially in those who suffer from anxiety or those with autism. It has been carefully designed to be discrete when deflated, and is self-inflating, so people can wear it under their coats without any obvious swelling, and enjoy a hug wherever they want.[24]

The latest life-saving equipment is also unusual. One device has been designed as a wearable bracelet which conceals a mini airbag, hence if a person is in danger of drowning, they can instantly trigger the device via a button, and the mini exposition inside will inflate the airbag and lift the wearer safely to the water's surface. Another example is the travel pillow, this pillow has been incorporated into a fashionable scarf, but has all the same functions as a normal travel pillow if inflated, making your travel more comfortable and elegant.

Although these applications still use conventional materials and are thus probably not sustainable, they provide a different perspective on how inflatable materials can be used, and demonstrate the diverse potential that these old materials have.

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[22] Will Mclean & Pete Silver, *Air structures,* (London; Laurence King Publishing Ltd; 2015) p.132.

[23] http://www.wired.co.uk/article/steel-goes-superlight (accessed September 2016)

[24] http://www.squeasewear.com/ (accessed September 2016)

CONCLUSION

From the pig bladder soccer balls of ancient times, to the inflatable metal stools of today, inflatable materials and technologies have developed significantly since their first iterations, and Thanks to the efforts of pioneers such as the Montgolfier brothers, Charles Goodyear, Buckminster Fuller, and Oskar Zieta, inflatable objects have continued to amuse, inspire, and benefit us in modern life. It is difficult to imagine a life without inflatable tires or soccer balls, and history will never forget the first hot air balloon that took humans to the skies, nor the inflatable decoy vehicles that helped Allied forces defeated the Nazis.

Each time a new material is developed, it brings with it new applications, these applications can significantly change the way in which we live, and hence the face of society as a whole. The ancient sheepskin rafts for instance facilitated transportation across the Yellow River, creating opportunities for commerce, and enhancing the lives of the people who lived on both sides of the river. The first hot-air balloon, which was made of linen and paper took humans to the skies and evoked a sense of social awareness in people. The invention of rubber tires stimulated the development of the automotive industry as we know it, changing the face of transportation and the landscape of modern cities. The invention of PVC not only influenced conventional industries, but had an impact on the art world, as well as architecture, and fashion. In the modern era, the Eden project showed people what could be achieved with the careful application of inflatable technologies. And most recently, the creation of inflatable metal stools and concrete canvas has shown how diverse inflatable materials can be.

Sustainability issues have long plagued inflatable materials, and many material scientists are trying to develop more environmentally-friendly materials. However, the diversification of occupations has gradually taken designers away from the lab. And the unstable physical properties of new materials, coupled with their relatively high cost and low yields makes them inaccessible. Sustainability is of course important to designers, but if they allow themselves to be constrained by the voices of critics regarding sustainability, they could miss lose out on important opportunities. But some designers do have the courage to engage in hard-core material engineering and cooperate with scientists, and some continue to exploit the potential of conventional inflatable materials in order to make the world a better place.

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