City membrane training platforms. Health-promoting Spatial Instalations for Children and Teenagers

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This article is inspired by the research on membrane training platforms, which has been conducted by the author for over two years. The author's experience, gained in the course of this scientific work, gave him the idea of applying a similar idea to health-promoting urban installations intended for children and adolescents. The author presents this concept against the background of currently known devices with a similar function and character. At the same time, he shows arguments in favor of the implementation of this unconventional proposal, justifying in detail the need to develop this type of activity for children and adolescents, and even for the elderly.

Genesis of the research

The research presented below has its origins in the cooperation between Wroclaw University of Technology and the "Lunares Space" Centre for creating a space for simulating human analog missions in a Lunar or Martian environment. The need arose there to simulate lowered gravity while walking on the lunar surface. A simple and economical solution to achieve this goal, turned out to be the use of a membrane surface, suspended the structure of an aircraft hangar. This cooperation gave rise to the idea of moving such platforms to city centers near schools or shopping malls, in order to stimulate the interest of children and youth. This would increase children's and adolescents' interest in the exploration of the solar system and, equally importantly, stimulate their proper body development, counterbalancing the negative impact of prolonged computer sitting, and the influence of modern diet, which can stimulate rapid bone growth.

The prototype of the platform is currently being installed in Tarczyn, in cooperation with the company, which has relevant experience in architectural membrane designing and performing.

Introduction

A modern and socially responsible City should promote healthy development and protect the health of the citizens. This protection can directly reduce the cost of treating injuries of young people and seniors. Injuries and fractures can undermine adolescents future physical activity, reoccurring into productive age, and may also affect seniors' life expectancy. It is unofficially known, that fractures in seniors take longer to heal, forcing them to endure longer hospital stays in an environment that is "contaminated" with other pathogens[1].

Undoubtedly, there is a growing awareness among parents and educators today that shaping from an early age, "atypical", spinal musculature of children protects them against injuries in adolescence. It is because there is a rapid growth of the body and destabilization of the musculoskeletal balance, resulting in e.g. scoliosis, affecting all later life. The implications of the current Covid-19 pandemic indicate that in the future, more and more popular in cities will be solutions for gyms and outdoor amusement parks. They will provide an alternative to similar functions organized in closed cubatures with often high[2] CO_2 [1] levels and artificial light.

The solutions proposed in the article belong just to the family of outdoor playgrounds in the form of economic training installations intended for children and adolescents, and in a specially adapted version, even for seniors [2].

According to the author, activities that increase spinal mobility should be the first stage when preparing the body and core muscles for short-term and dangerous overloads of the muscoskeletal system, which occur in other sports, such as team games, martial arts or due to a sudden loss of balance and fall. The platforms will also help to shape and calibrate the children's balance system [3], i.e. their developing vestibular system, which probably plays a crucial role in the development of many skills, such as eye-hand coordination, precision and spatial awareness of a child's body.

Parallel to the physiological and developmental advantages, the unconventional training installations proposed here can also be interesting architectural objects in urban space, inspiring to interact or take a close look at their attractive forms of rod - membrane structures.

Pro-health preresquisite

Physiological prerequisites for developing and maintaining a healthy body

Our posture, and thus the shape of our spine, undergoes many changes during our lifetime. There are periods of stabilization and instability [4], [6]. Those periods, when postural defects are more prevalent are called critical periods for postural genesis. Particularly active periods include the first 2 years, the 7th

1 Lorna Gibson in her lecture No. 11: "Trabelcular Bone, Osteoporosis" from the MIT OPEN COURSEWARE series, mentions that 40% of people over 65 who experience fractures or collapses, weakened by osteoporosis, experience significant body weakness caused by lack of exercise and, consequently, dies of pneumonia within a year of the incident. Annual American statistics (with an increasing tendency due to the aging population) say about 300 thousand hip fractures, and their treatment costs about $ 19 billion.

2 Measurements of the CO_2 concentration, carried out by the author with the ST303 SENTRY device, showed that, in popular shopping mall shops, "without windows" and in public transport, the levels ranged from 900 to 2300 ppm, while the concentration considered normal is about 400 ppm.

Author's archival drawings

year and puberty. Posture habits develop towards the end of pre-school age and postural defects are most commonly caused by unfavorable static positions, e.g. prolonged sitting in a school bench or carrying asymmetrical loads, as well as by the rapid development of the skeleton[3] [5] accompanied by a much slower development of the muscles which needs a systematic training. Bad posture habits are subconscious and result from the state of balance that is generated by an incorrect body arrangement. This results in contractures and excessive tension[4], which can lead to abnormal development of individual intervertebral disc [6]. The human body can be modelled as an interconnected system of compression and tension members in which the bones serve as the bars and muscles and tendons[5] serve as the cables. Therefore, a properly developed human musculoskeletal system, especially in the case of growing children and young people who regularly do sports, should be balanced, i.e. free of initial tension, contractures and muscle dystony. The treatment of such state is not easy as it requires a long and tedious and even painful process of applying force to the contracted muscles in order to loosen the fibers and restore them to their original neutral length. Therefore, it is beneficial to take action in advance, through prevention, by encouraging children and adolescents to perform exercises such as the passive hang and the dynamic hang while swinging on a trapeze or across the rungs of monkey bars.

The health of the spine strongly depends on the proper functioning of the feet. Orthopedists unofficially say that a child's foot can only be shaped for a few years and afterwards there is only prevention and "support". This is due to the complex structure of the foot, which contains numerous bones connected by joints, ligaments and tendons. Excessive load accompanied by the elimination of natural exercise accelerates the relaxation of the system and the collapse of the longitudinal and transverse arches of the foot. In a healthy foot, these arches act as springs and absorb loads, by storing the mechanical energy that is dissipated during arch deformation. In practice, when the foot is encumbered with load, its arches first lower and then return to their initial state once the load is removed. The problem is that although shoes protect the foot by providing an elastic support, they also make it “lazy" while walking. This is because the toes are not activated during the “rebound" action. These types of movements can be observed when moving barefoot on a soft surface, e.g. sand or grass, and they strengthen the muscles of the calf as well as the tendons connected to it which transmit forces (underneath the sole) from the toes. By supporting the foot as it rolls through the step from heel to toe, shoes cause the toes to lift and shorten the rolling motion to end on the forefoot, which than is under significant load.

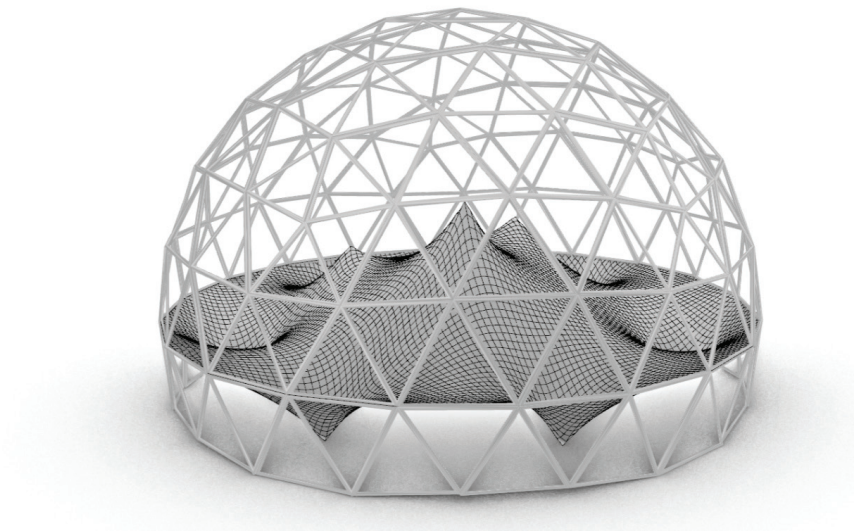

Fig.1. View of the model of the membrane training platform stretched on a geodesic structure with an equator diameter of 6 m, based on the technology of light, galvanized steel rods with small diameters, without gusset plates. The author of the parametric model: Szymon Łój

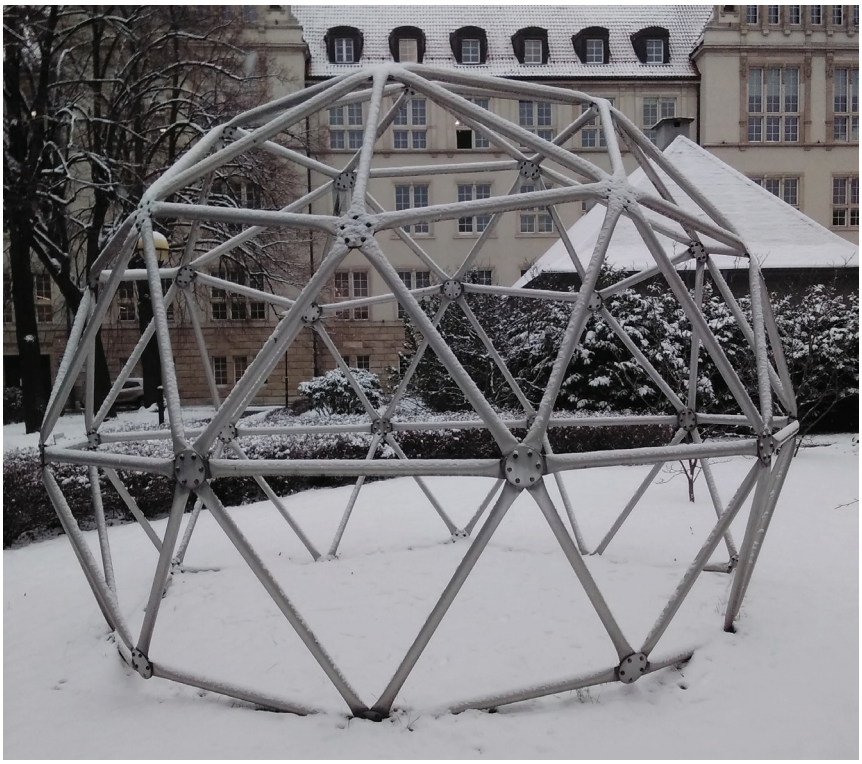

Fig. 2. Alternative geodesic dome structure. Technology of large diameter aluminum rods with gusset plates. Authors: Structural Research Group of the Wrocław Faculty of Architecture 2004: students: I. Fabrowicz, M. Marszał, A. Pilip, G. Tyrał, M. Witkowska, B. Zięba: supervisor: Prof. J. Rębielak

The characteristic structure of the human musculoskeletal system, its protection and prevention of injury

Practice and research show that human bones included in the weight-bearing structure have a high safety factor, i.e. a relatively high proportion of bone material, as opposed to muscles, tendons and connective tissues, in which case this factor is very low, close to their strength limit [7]. Sports injuries mainly occur because athletes are insufficiently prepared in terms of proprioception in the muscles, joints and tendons to withstand the mechanical forces and the extremely short time under load, that occur when training or competing. There-

[3] Anthropological studies show a significant increase in the mean value of height in the Polish population and other European countries.

[4] The so-called muscular dystony, i.e. disturbances in the balance of muscle tension (T. Kasperczak).

[5] In construction rod-tension systems there is a similar family of structures called "Tensegrity", and the method of rehabilitation using this model of chain relationships between individual sections of the human body is called the Tensegrity method.

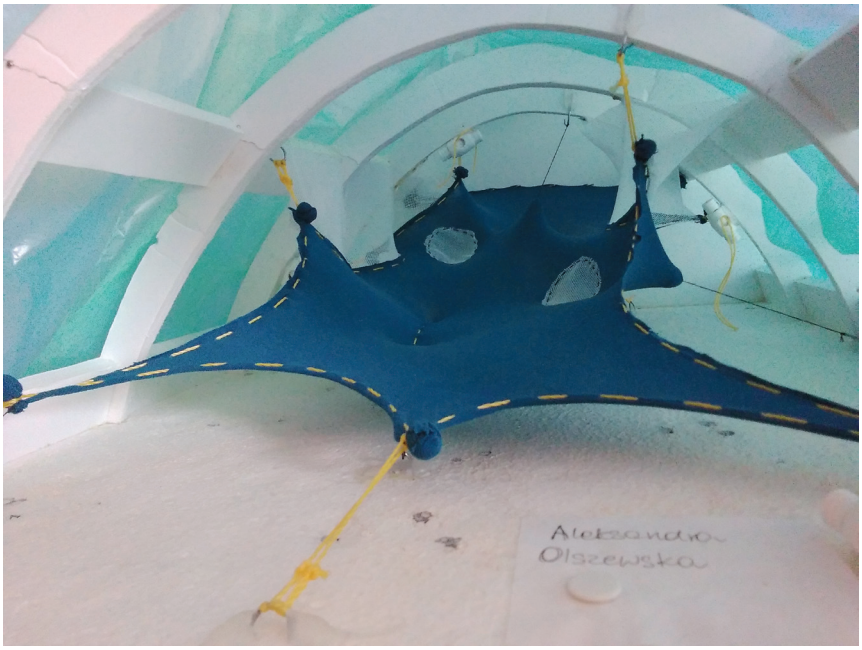

Fig. 3. The form of a membrane platform, stretched on arches - horizontal type. A large span of fields without suspension creates a platform with large deflections, introducing the "deep snow wading" mode. Author: A. Olszewska

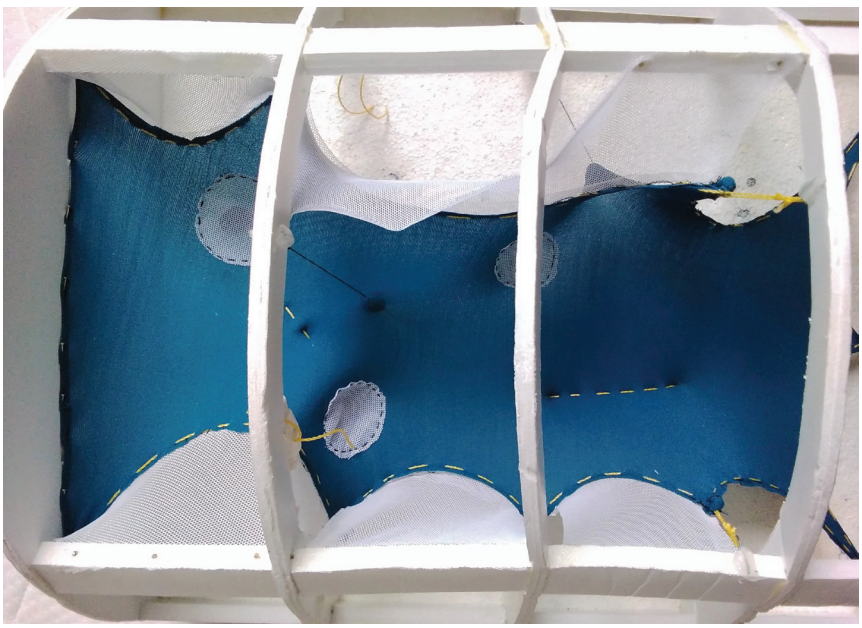

Fig. 4. Additional security net to protect the user from falling off the platform or falling into the "funnel" of the membrane. "Funnels" are a characteristic form of membrane surfaces and take the form of sudden lowers of the diaphragm to tension it and give it a rigid, two-curved surface. Author: A. Olszewska

fore, special attention should be paid to the strengthening of any flexible elements of the human musculoskeletal system and the points of attachment to the bones. Due to fact that the bone is adapting to changing loads, especially at a young age, regular training of young people will also structurally strengthen their bones along the axes of the main stress forces[6]. "This mechanism results from the higher blood supply in places subject to micro-injuries and from changes in the electrical potential that is generated in the bone during bending [8]. The stresses acting on the bones cause them to grow proportionally and transform fibrous bone into lamellar bone. What is interesting, the largest bone growths are recorded when it is under tension and the smallest under torsional loading [9]".

The structure and functions of the mambrane training platform

The platform in its basic state consists of: a load-bearing structure – in the form of a bar geodesic dome Fig. 1., and a PP[7] membrane, used in trampoline sports, or a synthetic fibre mesh, a system of tensioning springs and tighteners in the form of multi-block pulleys and hand winches, allowing the geometry and flexibility of the membrane to be changed. In the case of an installation using belts[8] and cables, these elements would be color-coded, according to their tension, as the most difficult and demanding task is to walk on a loose track. While in the case of membrane installation, its behaviour under load will be more like "wading" in deep snow than the behaviour of a traditional trampoline. Wading is more static and requires long-term involvement of many muscle groups and a sense of balance in a safe way in terms of possible injuries. The diaphragm tensioning system should also have deformation dampening features so that loading on one area does not excite the diaphragm in another area, e.g. 3 m away. Bars in the areas of collision with the user may be covered with the rubber insulators.

The platforms are to offer the most natural callisthenic[9] training, and by easy modifications of tapes configuration or the degree of membrane tension, they will keep the installation highly attractive. The advantage of such structures is their mobility because an experienced team can assemble or disassemble the structure of 6m diameter in almost a single day.

Polish market producer offers geodesic domes with several standard diameters of the equator: 6, 12 and 24 m. The company's structural designer also offers custom-made designs, for instance a system that connects structures with a different diameters. Well-designed forms are characterized by relatively high structural rigidity.

Installations suspended inside this structure pull its knots inwards, causing the near to force area to collapse in and pushing out of the opposite area, which deforms like the rim of a bicycle wheel without spokes. This problem is solved by tensioning of the internal installation of ropes, tapes, meshes or membranes, which on the one hand pulls the structure inwards, but on the other hand resists the forces that push the elements of the structure outwards. Its function is identical to the spokes on a bicycle wheel.

Domes may be covered with a membrane, but it is expensive solution and susceptible to damage in public spaces. The cover provides comfort on rainy days, but prevents walking on the outer surface of the dome. In all cases, the nodal bolts, connecting the bars of the structure, must have rounded protection of their sharp edges, e.g. in the form of climbing grips (like those realized by "Lifetime").

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[6] In mechanics, these are known as the directions of main compressive and tensile stresses in the bone.
[7] PP - abbreviation for polypropylene.
[8] In terms of high-strength and durable tapes or belts used in logistics and transport.
[9] Relying on resistance work with its own weight, without any additional strengthening devices.

In the case of the top sections of the structure, it is possible to stretch an additional net between them to protect smaller children from falling inside. User safety, can be ensured by putting sand on the ground or stretching a mesh net in less secure areas. The sandy floor can also be used to promote regular exercises without shoes on the sand to build the leg muscles and activate the systems in the feet so that they develop correctly and become strong.

If the membrane platform is installed on school or kindergarten grounds, it is possible to expand the offer by a virtual reality module which simulates walking on the surface of Mars or the Moon. It is then possible to introduce different task scenarios and interactions. At first, exercising in virtual reality on an elastic and curved uneven surface may cause perceptual distortions, which, after a few attempts and experiments are likely to become natural for users, thus extending their range of balancing skills. This type of activity would require the use of a harness, helmet and controlled suspension to the top of the dome

Classification of similar nature istalations

The analysis of selected, existing facilities allows to distinguish several main families of this type of solutions:

- **flat surfaces of PP fabric membranes.** designed for trampoline sport, stretched by springs on densely placed horizontal or inclined frames,
- **rope parks** in the form of rope footbridges and nets stretched on poles or trees,
- **linear objects in the form of loops,** i.e. paths made of mesh membrane[10] located on short columns above the terrain, stretched between two parallel pipes. Examples are the Schulberg in Wiesbaden or the "Corocord" loops,
- **rope playgrounds**, include objects such as towers, spatial networks, health paths with bridges and hyperbolic paraboloid surfaces. The supporting structure is usually vertical masts or bent arches, and the nets, with very large meshes are made of ropes connected with patented knots. An example may be the projects of the company "Corocord",
- **frame systems**, in the form of horizontal frames with mesh membranes stretched over them, which are suspended inside vertical portal frames, arranged with a spacing of several meters.

Examples illustrating this type of system are:

Netzvilla Schwabisch Gmund - the planes of the mesh membrane are inclined to each other and form the ramps. The transition between the planes is achieved by bonding the adjacent membranes and creating a circular opening. The side walls between the frames and ramps are secured with a net of steel cables "X-TEND".

Fig. 5. Vertical linear form, connected with a loop. Authors: S. Pluta, A. Wojtowicz, P. Muniak

A very similar principle of supporting structure for interconnected mesh membrane surfaces, but on a smaller scale, was used in the interactive two-story spatial sculpture, in the implementation of the "Numen / For use" group[11] in Hasselt in Belgium. Other projects of this group use internal walls of rooms.

A similar principle, but on a larger scale and with one membrane area, was used in the Brazilian Pavilion at the Milan Expo 2015 exhibition.[12] The meshed membrane surface, in cross section, adopts the geometry of a broad "V" letter and has a valley belt on the axis of the object and its edges rising towards the side walls.

At Showa Kinen Park in Tokyo, mesh membranes are suspended from a series of vertical columns and most often form surfaces with a hyperbolic paraboloid geometry.

- geodesic domes, in the form of playgrounds, composed of a rope meshes placed on the walls of a geodesic dome. An example here are the projects of the "Geos" company, which developed its own bar system with spherical nodes. Own system is very attractive visually, but it significantly increases the costs of a single implementation compared to the construction technique proposed in the article based on typical commercially available tubular rods with drilled and crimped ends, connected with a single bolt. This type of solution provides sufficient stiffness, the possibility of minor adjustments during assembly and easy disassembly.

[10] The design uses a construction mesh to protect objects or workers from falling.
[11] Christopher Katzler, Sven Jonke i Nicola Radeljkovic, www.numen.eu (11.01.2021).
[12] Studio Arthur Casas + Atelier Marko Brajovic.

Fig. 6. The form of a membrane platform, stretched to the arches - vertical surface type. This type of platform is much more rigid than the horizontal form and will allow, if implemented, to practice more or less complex climbing. Author: W. Dudek

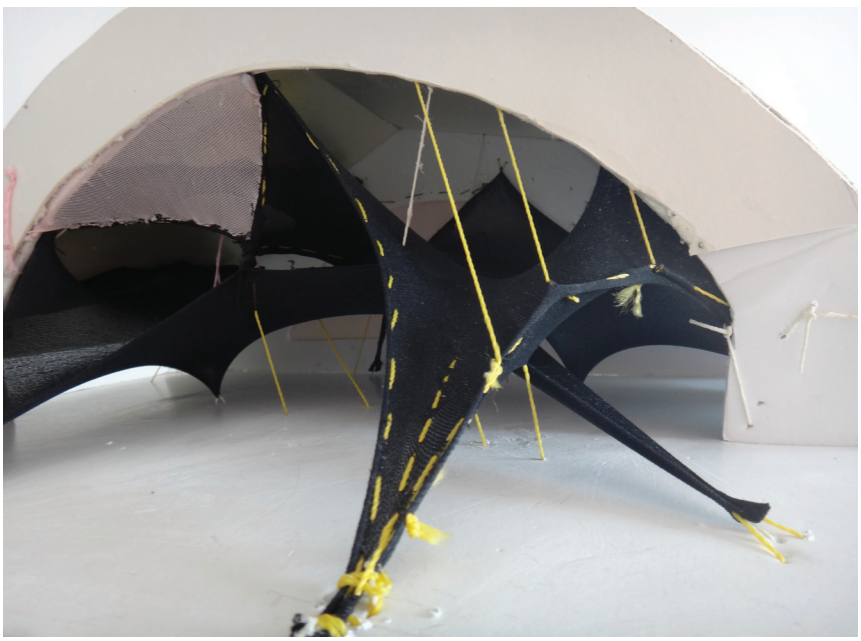

Fig.7. The form of a membrane platform stretched on arches - horizontal-vertical type. The entrance ramp is visible in the foreground. Author: N. Kuropka

Other possible variants of membrane platforms and their modeling

Interesting technology of the rod dome was proposed by the Students' Scientific Association of the Faculty of Architecture of the Wrocław University of Technology. It is more expensive than the ones discussed previously, but it is distinguished by the considerable attractiveness of its architectural form, Fig. 2.

Worth attention are the other works made by students of the same university, created in 2020 as a result of the didactic process aimed at searching for new forms of urban membrane training platforms, are also worth mentioning. Among them, five main families can be distinguished:

- horizontal surface, Fig. 3. and Fig. 4.
- horizontal linear - in the form of a loop
- vertical linear, Fig. 5.
- vertical surface, Fig. 6.
- horizontal vertical, Fig. 7.

The membrane supporting structure, realized in the form of arcs, can be made of bent pipes, hot-rolled sections or embedded trusses in reinforced concrete feet connected with ties. However, due to the costs of execution and construction, light bar systems will have the advantage of giving the possibility of making spatial forms, interconnecting domes, also with linear cylindrical forms. This type of light mixed structure can successfully become a skeleton on which a membrane, mesh, rope or tape will be stretched inside it. Forms of this type, made in a single-coat bar system with a hexagonal and pentagonal mesh, behave like flabby surface systems and will require reverse-chain modeling [10] or using minimal surface models similar to soap coatings [11]. These methods guarantee the achievement of natural forms, synergistically cooperating and balanced. Forms of this type are known to us from the Multihalla facilities in Mannheim[13] or from the form of covering the courtyard of the British Museum in London and the Smithsonian Institution in Washington[14]. In order to stiffen the shells spatially, it is necessary to use diaphragms in the form of openwork, bar-shaped surfaces, flanges and ribs or tension diaphragms used, for example, by J. Schlaich and his partners in the covering of the atrium of the Hamburg Museum[15] .

Conclusions

The functional essence of the presented concept of the membrane training platform is the ability to simulate the load conditions in a reduced gravity field by controlling the susceptibility of the substrate and its shape, which is unusual for the human senses. As a spatial object, this installation has a great potential in terms of shaping attractive architectural forms. According to the author, their presence in an open, public city space would be conducive to increasing the values of the urban environment.

A Modern City, having at its disposal the described membrane training platform, may implement a pro-health policy, increasing the level of trauma prevention among children and teenagers, as well as strengthening their spatial - motor skills, shaping their balance systems. The proposed installation, integrated with virtual reality, may also encourage seniors to mental training, stimulating their senses, regulating psychosomatic health and teaching safe fall.

Going beyond the strict scope of this article, it is worth mentioning other applications of the installation in question. The recipient of the membrane platform may also be the military environment, e.g. using the platform for training shooting positions and maintaining accuracy during running in the changing terrain. It is also possible to use a properly prepared membrane training platform as an installation supporting research and preventive activities by the Medical Academy and the Acade-

[13] The Architects: Frei Otto, Carlfried Mutschler, Joachim Langer. Engineers: Ted Happold, Ian Liddell, Brauer and Spah.
[14] Foster+Partners/Buro Happold.
[15] Gmp Architecten, von Gerkan, Marg + Partner/ Schlaich & Bergermann Partners.

my of Physical Education in the field of scoliosis [6], [12], development of the foot with reduced flat feet and improvement of the sense of balance and motor coordination of children and adolescents.

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Abstract: This article is inspired by the research on membrane training platforms, which has been conducted by the author for over two years. Currently, they are at the stage of building an experimental prototype in a real scale. These studies are the result of cooperation between the Wrocław University of Technology and the Center "Lunares Space - simulated space base" in Piła and the cooperation with the Academy of Physical Education in Wrocław regarding training devices.

The membrane training platform is a spatial membrane, mesh, rope or belt installation, stretched elastically on a light and economical, spatial rod structure.

A membrane is understood as a bi-curved surface, which is an unstable substrate, generating significant deformations under a load from a human walking on it - simulating walking "in deep snow" or in conditions of reduced gravity.

The author's experience, gained in the course of this scientific work, gave him the idea of applying a similar idea to health-promoting urban installations intended for children and adolescents. The author presents this concept against the background of currently known devices with a similar function and character. At the same time, he shows arguments in favor of the implementation of this unconventional proposal, justifying in detail the need to develop this type of activity for children and adolescents, and even for the elderly.

The presented proposals for new functional and spatial forms, intended for location in open space, are based on the use of low-cost, single-layer, octagonal and hexagonal bar systems, designed in such a way as to form closed systems, well absorbing forces from polypropylene nets, tapes or membranes stretched inside. According to the author, apart from their functional tasks, these objects could create intriguing, attractive architectural forms, enriching the city space

Keywords: membrane training platforms, health-promoting installations in city space, geodesic domes, membrane forms, core muscles, sense of balance, foot development

Streszczenie: MIEJSKIE MEMBRANOWE PLATFORMY TRENINGOWE. PROZDROWOTNE PRZESTRZENNE INSTALACJE DLA DZIECI I MŁODZIEŻY. Inspiracją niniejszego artykułu są prowadzone przez autora od ponad dwóch lat badania nad membranowymi platformami treningowymi. Aktualnie znajdują się one w stadium budowy doświadczalnego prototypu w skali rzeczywistej. Badania te są rezultatem współpracy Politechniki Wrocławskiej z Centrum „Lunares Space – symulowana baza kosmiczna" w Pile oraz współpracy z Akademią Wychowania Fizycznego we Wrocławiu w zakresie urządzeń treningowych.

Membranowa platforma treningowa jest przestrzenną instalacją membranową, siatkową, linową lub taśmową, rozpiętą sprężyście na ekonomicznym, przestrzennym stelażu prętowym. Pod pojęciem membrany rozumie się powierzchnię dwukrzywiznową, która stanowi niestabilne podłoże generujące znaczne deformacje pod obciążeniem od chodzącego po niej człowieka – symulujące chodzenie „w głębokim śniegu" czy w warunkach zmniejszonej grawitacji.

Doświadczenia autora, zdobyte w trakcie tej pracy naukowej, nasunęły mu koncepcję zastosowania podobnej idei dla prozdrowotnych instalacji miejskich przeznaczonych dla dzieci i młodzieży. Autor przedstawia tę koncepcję na tle znanych obecnie urządzeń, o podobnej funkcji oraz charakterze. Wykazuje równocześnie argumenty przemawiające za sensem realizacji tej niekonwencjonalnej propozycji, szczegółowo uzasadniając potrzeby rozwijania tego typu aktywności u dzieci i młodzieży, a nawet u osób starszych.

Prezentowane propozycje nowych form funkcjonalno-przestrzennych przeznaczonych do lokalizacji w otwartej przestrzeni oparte są o wykorzystanie niskobudżetowych, jednopowłokowych systemów prętowych – oktagonalnych i heksagonalnych – projektowanych w taki sposób, by tworzyły systemy zamknięte dobrze przejmujące siły z rozpiętych wewnątrz siatek, taśm lub membran polipropylenowych. Zdaniem autora oprócz swych zadań użytkowych obiekty te mogłyby tworzyć intrygujące, atrakcyjne formy architektoniczne wzbogacające przestrzeń miasta.

Słowa kluczowe: membranowa platforma treningowa, instalacje prozdrowotne w przestrzeni miasta, kopuła geodezyjna, formy membranowe, mięśnie rdzeniowe, zmysł równowagi, rozwój stopy