Publishing Series in PROJECT | Essays and Researches

Resilience between Mitigation and Adaptation
vol. 03 | 2020 | paper 7 | pp. 112-129

ISSN (print): 2704-6087
ISSN (online): 2704-615X
ISBN (print): 978-88-5509-094-0
ISBN (online): 978-88-5509-096-4

ADAPTIVE DIMENSION IN ARCHITECTURE
Modular and transformable structures as an alternative to traditional building systems

Annarita Zarrillo

section
Architecture

typology
Essays & Viewpoint

DOI
10.19229/978-88-5509-096-4/372020

Abstract
The ability to adapt is certainly one of the best qualities possessed by life forms on earth, an essential component for the survival of species. Talking about adaptation in architecture means conceiving the building no longer as a closed system, but as an organism that transforms itself to adapt to changing external and internal conditions. The research presented here shows the experiments of scholars who throughout history have supported and fuelled the concepts of transformability, transportability and adaptability. Among the 'pioneers' of the adaptive dimension in architecture, we find the famous architects Richard Buckminster Fuller and Konrad Wachsmann. The first linked its name to the geodesic domes: light, economic and transportable roofs, which can be used in various circumstances. Instead, Wachsmann's thought was oriented towards the innovation of construction procedures through prefabrication and standardization. Taking these two inventors as a starting point, it is possible to outline one of the most flourishing chapters in the history of architecture, where imagination meets the need to create extraordinary works.

Keywords
adaptability, transformability, prefabrication, Richard Buckminster Fuller, Konrad Wachsmann

Annarita Zarrillo is a PhD Student at the Department of Architecture and Industrial Design of the 'Luigi Vanvitelli' University of Campania (Italy), and an Assistant to the chair of Architectural Design of Professor Efisio Pitzalis. The research activity takes place mainly in the context of the Architectural and Urban Composition. She researches the evolutionary path of structural systems: from the archetype of trilithon, arch, and curtain to structures resistant in shape. Mob. +39 380/103.32.52 | E-mail: annaritazarrillo@gmail.com

Frei Otto wrote: «Our times demand lighter, more energy-saving, more mobile and more adaptable, in short, more natural buildings […]. This logically leads to the further development of light constructions, to the building of tents, shells, awnings and air-supported membranes. It also leads to new mobility and changeability. A new understanding of nature is forming under one aspect, the high-performance form (also called classical form), which unites aesthetic and ethical viewpoints. Tomorrow's architecture will again be minimal architecture, an architecture of the self-forming and self-optimization processes suggested by human beings» (Otto, 2004, pp. 6, 7). Conceiving the building as something heavy, immobile and permanent is a way of thinking linked to the past that has been overcome by a different idea of architecture. The transformable architecture leaves the designer the freedom to carry out reversible construction acts, such as covering or discovering a space, expanding or reducing a volume. These reversible constructions establish a unique link with the place in which they are inserted, thanks to their lightness, mobility, portability and change of shape[1] (Zanelli, 2003).

In recent decades, the demand for flexible and adaptable structures linked to a different concept of the building has grown strongly. No longer understood as an irreversible and permanent action, the construction process can adapt to the needs of a constantly changing society. This stimulated research and experimentation both in the field of transformable and transportable structures such as tensile structures and in the field of prefabrication and modularity. Today, scientific research in the field of tensile structures is mainly conducted by international associations. The most active ones are in the United States and Japan: ASCE (American Society of Civil Engineers), MSJA (Membrane Structures Association of Japan) and IFAI (Industrial Fabrics Association International). There are similar realities also in Europe: IASS (International Association of Shell and Spatial Structures – Spain) and TensiNet (Belgium).

In the field of prefabrication, on the other hand, today's industrial production methods have significantly exceeded the concept of standardization in the traditional way. The new frontiers of research have focused on digital fabrication, a method based on computer-aided design and production with CAD/CAM software. These technologies are used in the production sector to manage robots and Computer Numerical Control (CNC) cutting machines. The central core of this publication is the concept of adaptability, which is explored by following two paths. Considering the state of the art, this publication aims to show, how throughout history, there has been a tendency to make architecture adaptive. On the one hand, through the evolution of the architectural form following the inventions of Frei Otto and Buckminster Fuller. On the other hand, through the automation of industrial processes, an extreme consequence of the experiments of Walter Gropius and Konrad Wachsmann.

Adaptive architecture | In the design process, the building is like a system that interacts with other natural and artificial systems. Each element of architecture cannot be released from the context in which it is located because it is in constant relationship with its surroundings. This makes the building a dynamic system subject to internal and external actions due to time, atmospheric agents and users who use it. The adaptivity of a system is the ability to modify itself to react to a change so that it can continue to perform its function even in conditions that differ from the original ones. This gives the system resilience. Changing according to needs and circumstances is an essential value of adaptive architecture. Adaptive systems change structure and behaviour based on demand, to adapt to environment and users. Those structures, designed with the specific intent of making them adaptable to changing human or environmental needs, are identified as adaptive architectures. Herein lies the difference between adaptable and adaptive: each architecture is in a certain quantity adaptable since it can be adapted to the needs in a manual and cumbersome way, but only an architecture born with this specific intent is called adaptive. The design strategies used to ensure that architecture is adaptive are mobility, which makes structures transformable and transportable, and standardization.

Transformability, transportability and adaptability | Transformable structures are convertible constructions capable of changing the configuration in the shortest possible time, through geometric and kinematic passages. The key criteria for their design are the time to switch from one configuration to another and the period of stay in each of them. The large transformable roofs have the aim of being able to adapt to sudden atmospheric changes. So, the movements must be so fast that it does not take more than a few minutes. This ability is called 'climate adaptability'. In the case of constant weather conditions for longer durations or temporary roofs calculated only for a specific period, we talk about structures that respond to 'seasonal adaptability'. The transformation process may, therefore, be longer and less frequent.[2]

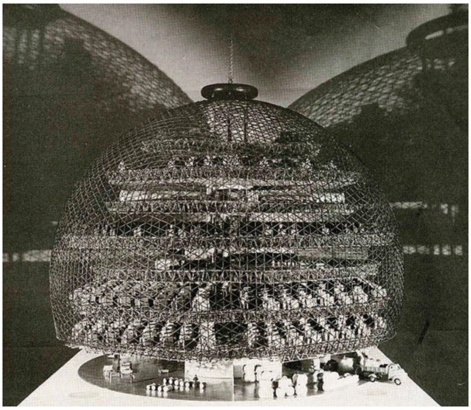
The need to ensure the continuity of outdoor events: sporting, recreational, cultural or religious, has greatly increased the interest in transformable structures. A convertible roof can safely guarantee the possibility of being outdoors and taking advantage of ventilation and natural lighting. In the event of adverse conditions, on the other hand, it protects users from rain, wind or snow. Also, it can shade and repair the space below in a variable way, allowing, for example, the growth of natural grass on football fields. Investors are strongly attracted by the adaptability and transformability characteristics of these roofs, so much so that they have preferred them to traditional fixed roofs on various occasions. In fact, retractable roofs are not only used in sports, but also for ships, cars, planes and exhibition spaces. The urban spaces and private residences also exploit several tensile structures of this type (Zanelli, 2003).

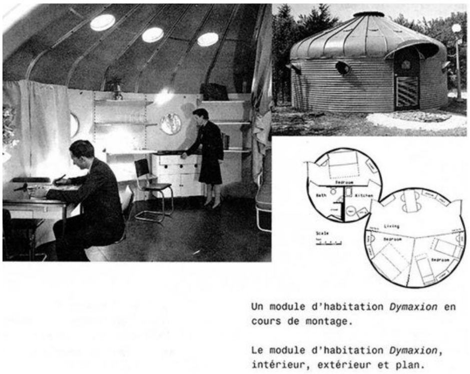
The first mobile structures | The oldest mobile settlements are those of the nomadic populations who lived near the Dnestr River, west of the Black Sea, during the ice age[3]. Occasional tents and huts were assembled quickly using mammoth bones as a structure. Later, other materials were also used, such as horns, trunks, branches and reeds. The progressive improvement of the construction technique has led to more advanced tents, which respond to the basic need of nomadic peoples to be transported. The adaptability of these systems consisted of being able to place them in different environments, giving them different configurations based on the climate and needs. The main transformations concerned the roof, partially closed or open, and the internal volume which depended on the number of support poles. Depending on the climatic conditions, the tent could take on a less capacious shape but more resistant to strong winds, or wider and more open during periods of warm weather.

A significant example is the 'yurt' tent, still used today by nomadic peoples living between Mongolia and China[4]. Roman civilization, on the other hand, was the first to refine the technique in the use of retractable membranes. In fact, the Romans had a deep knowledge of membranes thanks to their experience in navigation. The skills acquired on the boat sails folding and unfolding were reused to create the first convertible shading systems. The disused sails were reused to cover large spaces, for this reason, Vitruvius, in the Augustan era, called them 'velarium'. Other uses of mobile structures could probably consist of modular scaffoldings, used in the Middle Ages for the great construction works of the cathedrals. In the Renaissance, however, according to written records, primitive mobile structures were used to support objects[5] (Escrig, 1996). More recently, numerous experiments have been carried out by world-renowned architects and engineers, among whom it is right to mention Buckminster Fuller and Frei Otto. Starting in the 1950s, Fuller and Otto developed light construction systems which then became the new structural archetypes of contemporary architecture: tensile structures (Nardi, 1986).

Buckminster Fuller | In the first half of the 1900s, important mobile structures were designed by the American architect Richard Buckminster Fuller: the folding geodesic domes, the tensegrity structures and the Flying seedpod. He studied the potential of trusses and construction systems based on the repetition of an elementary structure and the standardization of simple elements. Its novelty consists in the choice of materials and production and assembly techniques obtained from the most advanced sectors of the industry. Its architectures were designed to be mobile and transportable. Scholar of Le Corbusier, Fuller takes the concept of 'machine à habiter' to the extreme by proposing the 4D House project in 1928, a real home machine.[6]

Transported by air, this house guaranteed a remarkable dynamic installation comfort. However, all his projects remained prototypes, finding no outlets in the industrial marketplace. On the other hand, he defined himself as an 'inventor' rather than a manufacturer, in fact, he secured up to twenty-five patents in the United States. Its goal was to change the concept of housing, but ironically, its innovations were used only for non-domestic uses, such as pavilions for fairs or radar housings. An exception was the brief use of geodesic domes in some hippie communities of the 1970s. Subse-





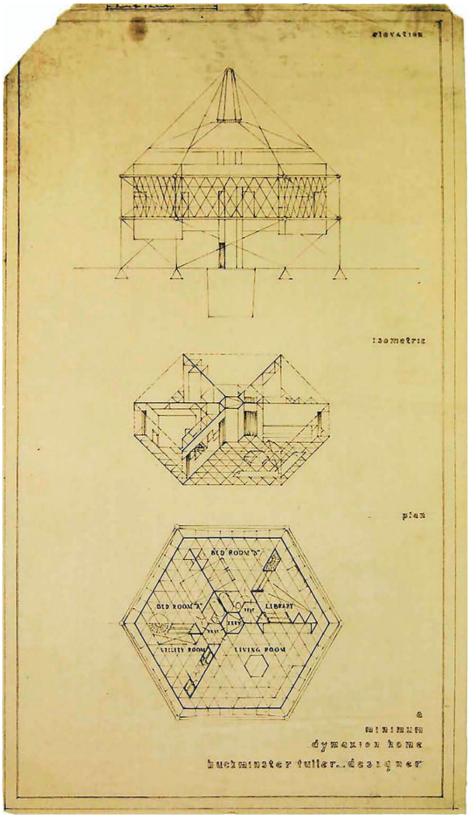


Fig. 1 | Richard Buckminster Fuller, Enclosed within a geodesic sphere of short steel components, the seven production floors assume a mushroom shape which would be enclosed with a stretched plastic skin (credit: Architectural Forum, n. 141, 1952).

Fig. 2 | Richard Buckminster Fuller, Dymaxion House (1940).

Fig. 3 | Richard Buckminster Fuller, minimum Dymaxion Home, exposed to MoMA, New York, 2002 (credit: Envisioning Architecture n. 65, 1927).

quently, he decided to change the name 4D to Dymaxion, from Dy-namic, Max-imum, and tens-ion by their aptitude for dynamism and transportability (Fig.1).

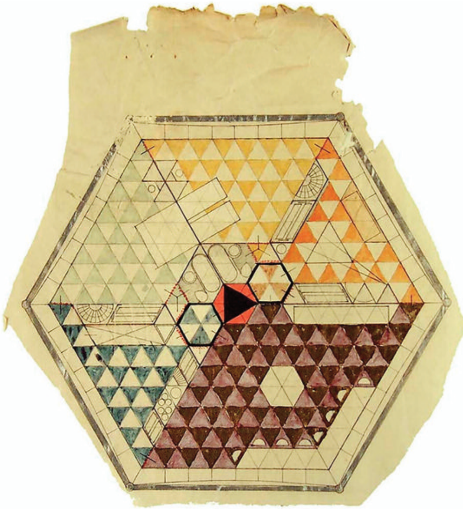
Later he designed several derivatives of the Dymaxion House which he published in the magazine 'Shelter'. Among the various solutions he designed, the best known is the DDU (Dymaxion Deployment Unit), made in 1940 for the British War Relief Organization (Fig. 2). The request was addressed to the construction of emergency houses to be used during the war periods. A few dozen DDUs were made of galvanized steel and used as test models in the Persian Gulf region. However, the impetus of the war led to a shortage of steel and thus industrial production of these homes could not be started. For the post-war economic recovery, Fuller created a housing model that combined the suspended structure with a central 4D antenna with the roof design and circular plan of the DDU and he named it Wichita House or Dymaxion Dwelling Machine (Figg. 3, 4).

Again, only a few prototypes were made. The next step in Fuller's studies was the creation of the Standard Living Package (1947-1952) which consisted of solutions based on rectangular modules mounted on castors. Subsequently, Fuller developed the roof by making low-cost geodesic domes. Soon this line of research proved to be of such importance that it occupied the rest of his career. The culmination of Fuller's projects was the creation of DIY domes made from recycled materials. These were structures that could be inserted in any context by being in harmony with nature. Thus, anticipating the theme of ecology that would have been fundamental in the following decades. Fuller's housing solutions share the same static scheme: the structure is assembled from a single vertical support element and a horizontal system with tension cables. These are the first tensile structures applied in a housing unit.

Furthermore, it was Fuller who coined the term 'tensegrity' by combining the words 'tensile' and 'integrity', to describe structures that worked with elements subject to compression connected by a dense network of cables in tension. The ease and speed of construction make tensegrity a transportable even if a not completely transformable system since once assembled, the forces involved are carefully measured to make it stay rigid and firm. The latest developments have joined the tensegrity of electrical mechanisms capable of decreasing and increasing the stress inside the cables so that the structure can be folded and unfolded. Another Fuller invention was the Flying Seedpod, a large folding structure made up of rods connected by joints. The system derives directly from the studies made on geodesic domes and tensegral structures. However, no real realizations were ever made (Gorman, 2005).

The geodesic domes | Of great importance in the design of the geodesic domes were Fuller's studies on the Dymaxion Air-Ocean Map, a cuboctahedron planisphere created in 1943 (Fig. 5). The same system used for the planisphere helped him to draw on a sphere a series of maximum circumferences corresponding to other regular and semiregular polyhedra[7]. Fuller, in fact, realized that the maximum circumferences allowed to draw on the sphere a skeleton with interesting geometric and structural properties (Fig. 6). But the particular resistance of structure comes into play only if it is suspended for the central node, otherwise, the structure becomes unstable. So Fuller was attracted precisely to the concept of instability and began to experiment with the use of models with flexible rubber knots. Starting from the cuboctahedron, he realized that by pressing on one of the triangular faces, the central body twisted assuming some intermediate configurations: cuboctahedron, icosahedron, octahedron and then tetrahedron. By releasing the model, it returned to its original form (Fig. 7).

These discoveries have become the basis for future developments in the field of transformable and transportable structures. Geodesic domes were the invention that



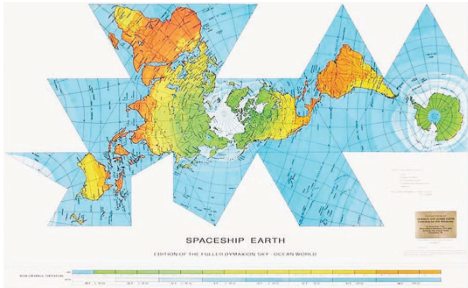
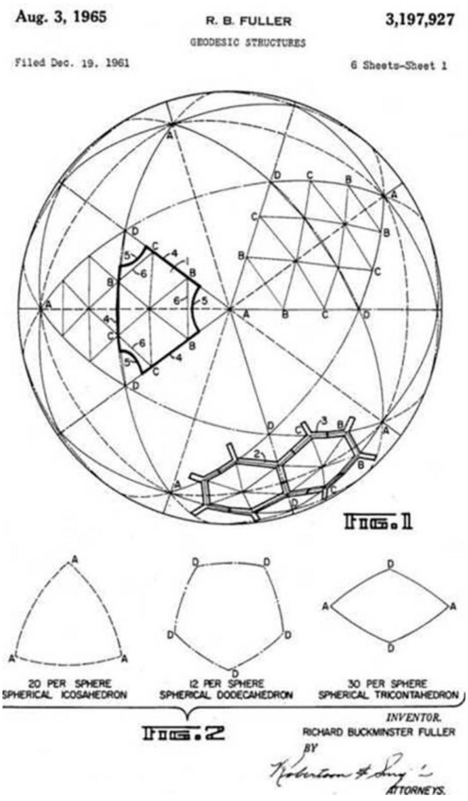


Fig. 4 | Richard Buckminster Fuller, Plan of Dymaxion Home, exposed to MoMA, New York, 2002 (credit: Envisioning Architecture n. 64, 1927).

Fig. 5 | Richard Buckminster Fuller, Dymaxion Air-Ocean Map.



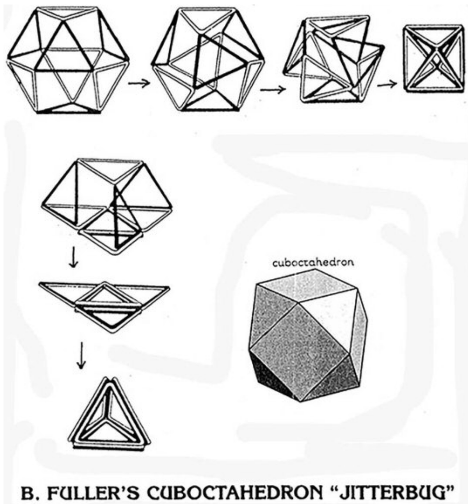


Fig. 6 | Richard Buckminster Fuller, Structure of Geodesic dome, 1965.

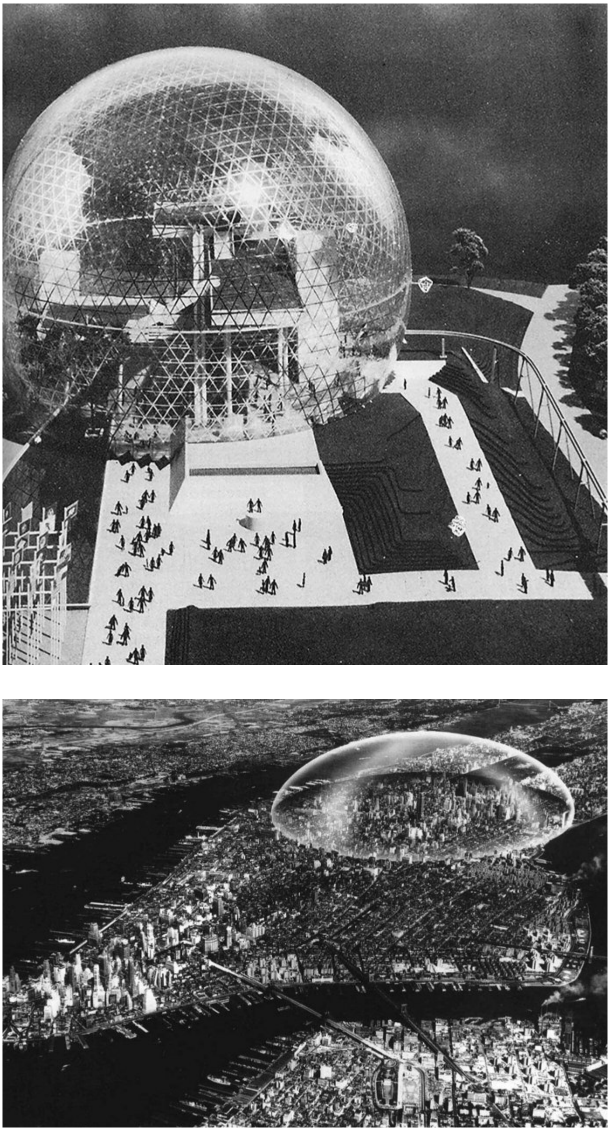
Fig. 7 | Richard Buckminster Fuller, B. Fuller's Cuboctahedron 'Jitterbug'.

made Buckminster Fuller well known in the scientific world. The structure of the domes is composed of a complex network of triangles that make it structurally very strong, easy to build and self-supporting. The first dome designed in 1949 had a diameter of 12.8 meters and was made up of aluminium rods deriving from pieces of aircraft pipes. These flowed into hinges that allowed their packaging. In the closed configuration, the sphere appeared as a bundle of easily transportable parallel elements. To operate the opening mechanism, it was necessary to position the pile of rods in a vertical direction and apply a pulling force through the use of ropes attached to some hinges. In this way, the pneumatic pistons placed on the vertices and responsible for the movement were activated. Fuller had provided a transparent polyethene membrane on the lower surface for thermal insulation (Fig. 8).

The idea of a similar structure was born from the attempt to solve the problem of lack of housing. In 1954 he obtained the patent for geodesic domes. He continued to experiment with increasingly large spheres, up to diameters of about 120 meters, which he planned to transport with the use of planes. In 1968 he even had the idea of designing an immense geodesic dome of 3 km in diameter called Dome City, which covered the entire city of New York to mitigate its climate (Fig. 9). In Italy Fuller's geodesic domes were presented at the X Triennale di Milano in 1954 and in specialized magazines that dealt with it. Two specimens were built, one used as a dwelling and the other as an exhibition (Marks, 1960).

Frei Otto | One of the first architects to question the functioning of light structures was the German scholar Frei Otto. He placed the lightness and optimization of the structural elements as the founding paradigms of his works. His strong interest in the natural world prompted him to seek essential constructions that explicitly showed their natural constitution processes. As far as flexible architecture is concerned, Otto traces the natural pattern of tensile structures in the spider web. The model for pneumatic structures is instead traced in the minimal surfaces of the soap bubbles, with which the first study models of the compression structures were developed (Fig. 10). Together with his collaborators, Frei Otto built-in 1955 the first entirely membrane tensile structure with steel edges for the Federal Garden Exhibition in Kassel. The music pavilion, called Bandstand, consisted of a quadrangular fabric sail, with a characteristic saddle shape: two opposite vertices were pulled upwards and tied to two pine poles and the other two anchored to the ground. In the first half of the 1960s, he studied the first convertible roofs, even large ones. These are not yet global retractable systems, but membranes that are opened and folded on a fixed and permanent support structure.

The primitive retractable experiments, therefore, overlap with the progress in the field of permanent tensile structures. In the same years, the Institute for Lightweight Structures of Stuttgart founded precisely by Frei Otto in 1964, developed the classification scheme of the different construction types. This was drafted thanks to tests, made on scale models, which analysed the movement modes. In the beginning, roofs were built



Figg. 8, 9 | Richard Buckminster Fuller: Geodesic dome model (credit: Calli, n. 24, 1966); Dome City.

that were not completely transformable because they consisted of a fixed cable structure, for supporting and sliding the canvas. As for the Roman ‘velaria’, the two main methods used were: the unfolding with respect to parallel beams, or the radial opening of the membrane starting from a configuration which was suspended and collected in the centre of a circular area. The continuous research of Frei Otto and his collaborators on this type of transformable structures laid the foundations for the subsequent design of the Olympic Stadium in Montreal, on the 1976 games hosted in Canada (Fig. 11).

Tensile structures | Tensile structures are light, flexible, removable and retractable architectures, suitable for configuring both permanent and durable and semi-permanent and temporary spaces (Capasso, 1993). Thanks to their use, it was possible to obtain that lightness and freedom of forms in the roofing which are its most exciting features. Among the suspended roof structures that we remember most there are: the Tokyo Olympic complex of 1968, the Olympic complex of Munich in 1972, the stadiums of Turin and Rome and the tent coverage of the Jeddah air terminal. The principle of using ropes in a roof is documented for the first time in 70 AD. for the coverage of the Roman Colosseum of 189 x 156 meters.

From a technical point of view, tensile structures include cable-stayed structures, suspended systems, cable girders, cable nets and membrane tensile structures (Fig. 12). In particular, these can be divided into two main types: the actual membrane structures and the pneumatic structures. In fact, these types of structures are made with very flexible and extremely light membranes (typically 0.7-1.4 kg/sqm), with a level of pretension that generates rigidity in the surface. This state of tension is obtained using flexible elements such as cables or by increasing the surface curvature through ridges and valleys. The load-bearing capacity is given by the pretension and the double curvature impressed on the surface (Forster et alii, 2007). The pneumatic structures instead develop resistance to accidental loads through the action of pressurized air placed inside them. They can consist of one or more layers of material. In the former, the pressure difference is established between the internal and external environment. In the latter, the significant pressure difference is between two or more layers of material (Schock, 2001).

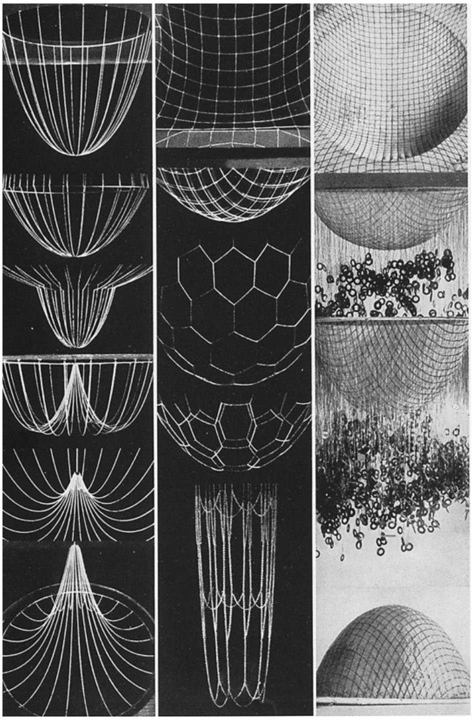
Modularity and Prefabrication | Modularity and prefabrication have ancient origins. In the past, the actual design phase was reserved for buildings of worship or power. Instead, the common building was based on combinations of different materials and techniques, depending on availability. Implicitly, the concept of modularity was immediately placed based on construction practice. The technical knowledge, purely empirical, was handed down from generation to generation and prepared the rules, dimensions and proportions to be respected for the construction. The concept of prefabrication instead followed a slower path, which intensified only after the first industrial revolution. In fact, producing buildings with assembly techniques and prefabricated elements requires adequate mechanization of the construction site and companies specialized in the production of materials. This technological evolution in the construction sector did not begin before the 19th century.

The traditional entrepreneurial structure, strongly based on craftsmanship, and the low market demand have contributed to further delaying the development of a prefabricated building. The prefabrication of building can be considered as a proto-industrialization phase, a term of transition towards more integral industrialization, which reduces the site activity almost exclusively to a sequence of dry assemblies. The development of prefabrication owes its origins to the need to build affordable housing in rapid urbanization phases, as after the Second World War and for the displacement of population from the countryside to urban centres (Fig. 13). The diffusion of prefabricated became imposing and significant starting from the post-war period, even if illustrious previous examples are not lacking: prefabricated houses were shipped from England to the English colonies in Massachusetts in 1624. Later, in 1790 an entire village was shipped to Australia and in 1820 similar cases were repeated in South Africa (Osayimwese, 2009).

Walter Gropius | Born in Berlin in 1883, Gropius studied at the city's technical school and at the Munich school. In 1911 he was a member of the Deutscher Werkbund and in the following years, he was part of the German avant-garde groups, active in wanting to create a new architecture. In 1919 he founded the Bauhaus, Weimar state school, obtained from the merger of the school of applied art and academy of fine arts, which he had already directed since 1916. Ha intended to retrain German craftsmanship by rationalizing the industrial production of construction elements and components. Gropius believed that the teaching of an artisan craft should prepare for design of mass products, typical of industrialization. This is because the simple tools used by the craftsmen allow you to master the most complicated problems with great skill and to know how to solve them. So, for Gropius, the role of the craftsman had to change and evolve into a designer who wisely uses his technological knowledge. Fundamental themes of his career were: prefabrication in wood, the industrialization of the construction site and cost-effectiveness, also given by the reduced construction times.

Konrad Wachsmann | Konrad Wachsmann is a German-born American architect. In 1950 he became a design professor and director of the Institute of Technology in Chicago. A pioneer in the field of prefabrication, he has made numerous experiments in search of basic module suitable for all construction needs. These modules were designed to be able to configure multiple combinations and were composed of materials suitable for mass production. (Fig. 14) Wachsmann was a pupil of Tessenow in Dresden and Poelzig in Berlin, where he trained as an architect in the prefabricated wooden construction sector. In 1940 he associates with Walter Gropius in the United States. This collaboration leads to the utopian vision of a prefabricated house. In 1942 they presented a prototype for a modest house, which could be built with a wooden frame and panels. The Packaged House was approved, generously funded by the government and well marketed, but the company did not sell houses after the end of the war (Fig. 15). Fortunately, between 1941 and 1948, Wachsmann had a second chance with a government-supported housing program for veterans. On this occasion, he designed the packaged house system for the General Panel Corporation.

Altogether, of the 10,000 houses that the company was supposed to build each year, 200 were produced and only a few were sold. Between 1944 and 1945, Wachs-



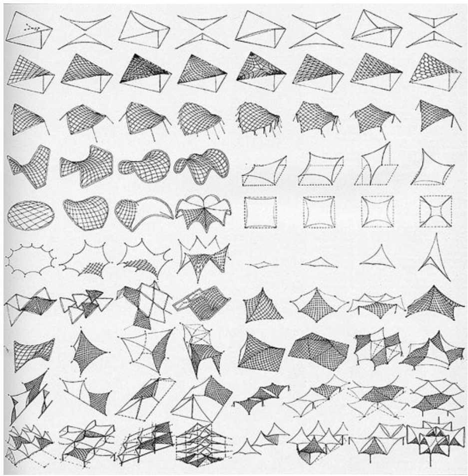


Fig. 10 | Frei Otto, Experimental models of research of the shape with catenaries and soap bubbles (credit: Casabella, n. 301, 1966).

Fig. 11 | Frei Otto, German Pavilion (credit: Montreal World Expo, 1967).

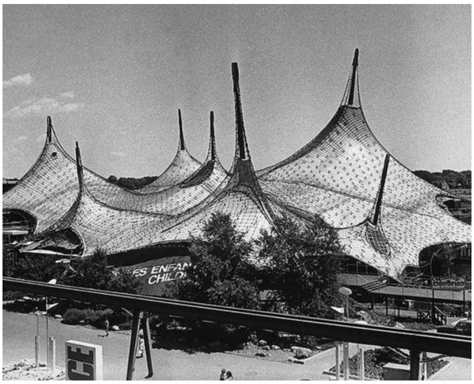


Fig. 12 | Frei Otto, Tensile structures diagrams (credit: Casabella, n. 301, 1966).

mann designed the Mobilar Structure for the Atlas Aircraft Corporation. It consisted of a system of movable wall surfaces in steel. The highlight of Wachsmann's research is the hangar prototype for aircraft of exceptional size, based on a system of prefabricated components, developed on behalf of the USAF since 1951 (Fig. 16). This is a spatial reticular structural system with tetrahedral development made of steel pipes converging into an exceptional universal node, capable of accommodating up to 20 pipes (Eaton, 1962).

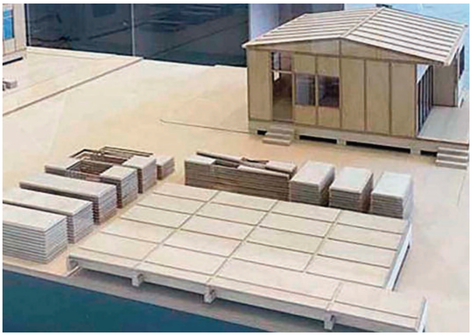


Fig. 13 | Jörg Zimmermann, Model of the housing prototype Packaged House System (Stylepark).

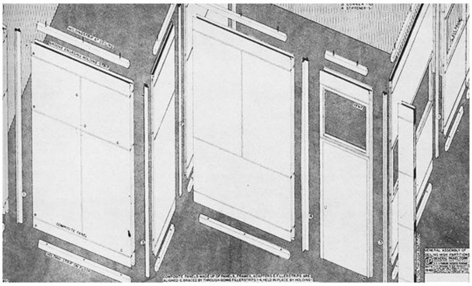


Fig. 14 | Konrad Wachsmann, Prefabricated wooden panels (credit: Casabella, n. 244, 1960).

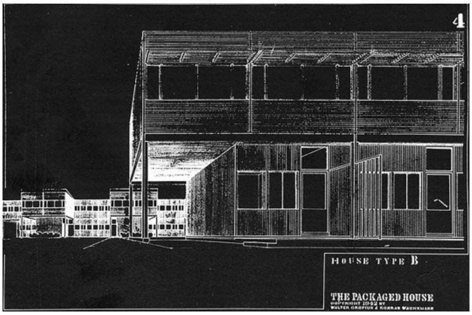


Fig. 15 | Walter Gropius and Konrad Wachsmann, House type B of the Packaged House System (credit: Interiors, vol. 103, n. 5, 1943).

Packaged House System | The Packaged House System project (1941-48) consisted of a system for producing prefabricated wooden houses developed by Konrad Wachsmann in 1941, in collaboration with Walter Gropius. It was then produced through the American company General Panel Corporation. It was a three-dimensional design system based on a 120 cm modular grid on which to combine the infill panels, partitions and roofing elements. (Fig. 17) The prefabricated wooden walls were industrially produced with the scrap of 0.06% of the material. The characteristics of the components were such as to allow adequate compositional flexibility, strongly directed to the usefulness and speed of execution (Wachsmann,1992). This system made it possible to build houses with 1 or 2 floors above ground, without the use of special workers. In particular, the innovation of this device consisted in the invention of a cubic-shaped

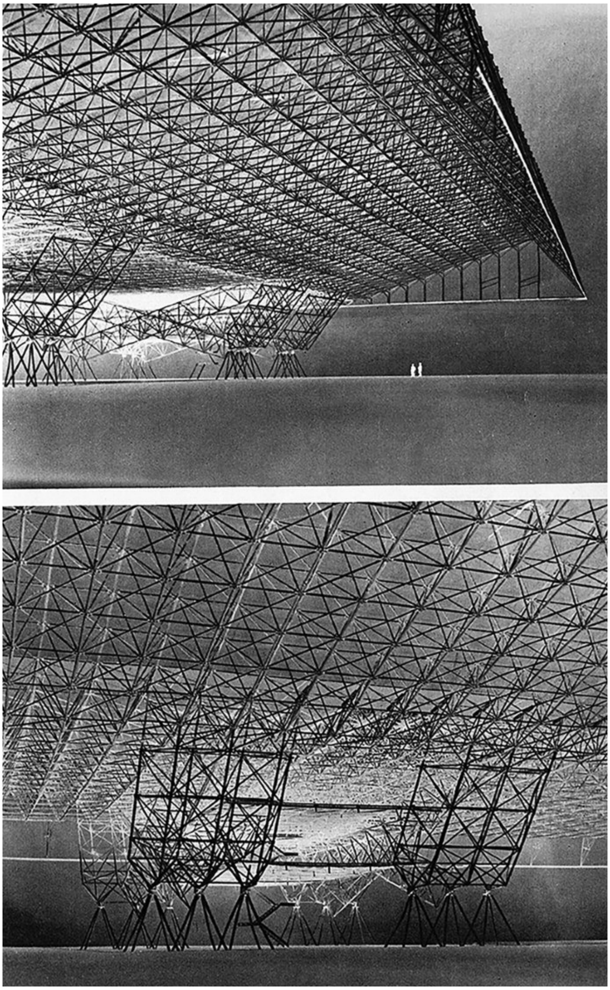


Fig. 16 | Konrad Wachsmann, Spatial reticular structural system with tetrahedral development (credit: Domus, n. 302, 1955).

universal joint in wood, in which twelve panels converged. It is a universal standard steel node, made invisible by the panels attached to it (Fig. 18).

The connecting element, divided into four parts, allowed the installation of the same components in the horizontal and vertical directions. The prefabricated wooden components consisted of frames with load-bearing and stiffening functions. Each panel package consisted of two jointed panels so that an insulating layer could be inserted inside them. The space of the openings was standardized within the framed structure and could have variable heights according to the needs (Fig. 19). During the testing phase, the prototype was assembled in 8 hours. In 1955 the production of the Packaged House System was stopped due to the high costs of the raw materials used, the waste of materials that involved the workings and the excessive num-

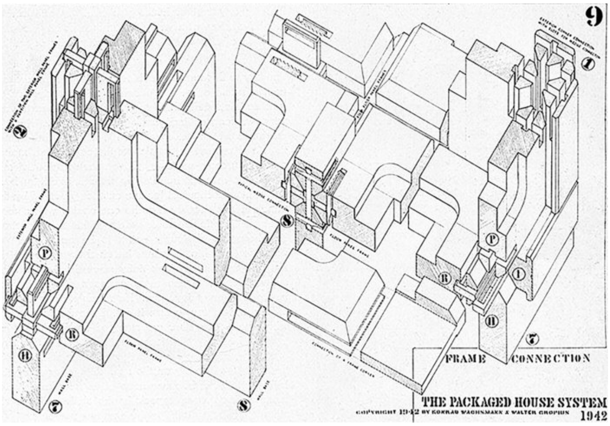


Fig. 17 | Konrad Wachsmann and Walter Gropius, Frame connection of the Packaged House System (credit; Interiors, vol. 103, n. 5, 1943).

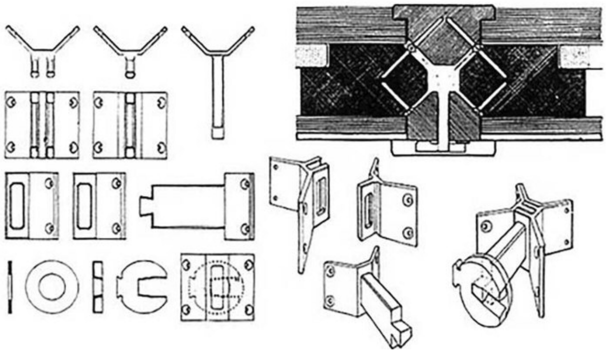


Fig. 18 | Konrad Wachsmann and Walter Gropius, Steel connection to fix the panels of the Packaged House System.

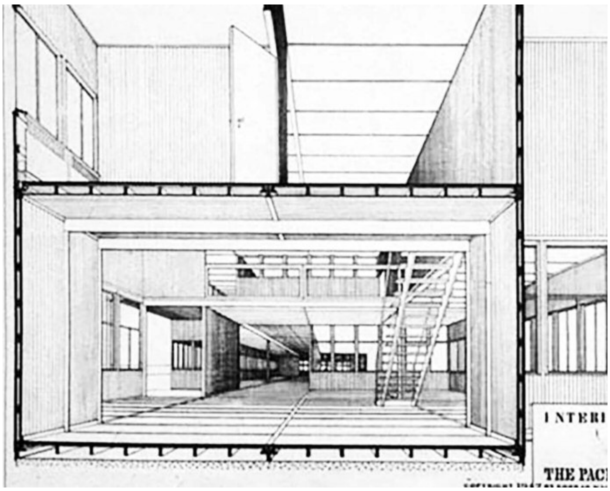


Fig. 19 | Konrad Wachsmann and Walter Gropius, Perspective section of the Packaged House System. (credit: Interiors, vol. 103, n. 5, 1943).

ber of workers required for each production line (Rodríguez and Monrabal, 2011).

Final considerations and possible future developments | The current environmental situation leads us to ask what role new architecture will play in the contemporary critical context. That sustainability must permeate the entire design process is now an axiom. Therefore, the designers are called to use appropriate technical solutions, products and materials, to obtain buildings with high energy savings and zero impact. These are the guidelines for conceiving the building as a flexible and integrable system, capable of adapting to increasingly stringent climatic and environmental needs. In the context of technological development, the automation of industrial processes increasingly offers the opportunity to produce and manage products that are: adaptable, reversible, reusable and recyclable. Each of these aspects makes the project more compatible with the environment as it limits damage to the ecosystem.

The removable and transformable structures have a very wide field of application that includes both new buildings and interventions on the existing building heritage. When designing from scratch there are many viable technical solutions, instead of in the recovery interventions the field narrows to the solutions that can be reconciled with the constraints imposed by the pre-existing ones. In these interventions, the characteristics of reversibility and variability of configurations are particularly useful. Another field of intervention of the reversible structures concerns the recovery and reuse of the minor building fabric. In particular, textile membranes are able to give new identity and a new function to the resulting city spaces. Characterized by a great lightness, the membranes transmit a sensation of physical inconsistency that allows a volumetric redefinition of architecture, without being invasive. Thanks to the characteristics of lightness, ductility, reversibility and transformability, textile structures can find new application scenarios.

The use of transformable structures of this type represents only the first step towards a new way of conceiving architecture as dynamic. In fact, adaptive architecture can change its shape and function, it can be dismantled and assembled several times to form unprecedented structural types to be used in different places and for different purposes. In the near future, this renewed architectural concept could provide a valid alternative to traditional, secular and immutable building systems. The innovation of our times consists precisely in overcoming the concept of building as a closed system that only works in a given place and at a given moment. Rather, it should be considered as an organism that transforms over time, so as never to become obsolete.

For completeness, it is necessary to remember, alongside the obvious advantages, also the disadvantages that a designer must face when confronting transformable structures. Being relatively new materials and construction types, the lack of precise design indications to follow is certainly an unfavourable point together with the high initial cost due to the need for highly qualified professionals. In conclusion, the current scenario is projected towards the increasingly absolute integration between the world of industrialization and that of construction. Structures belonging to the field of adaptive architecture require a greater effort by the architectural designer. Therefore, during the training course, it becomes necessary to acquire sufficient knowledge to form the 'design sensitivity' or 'physical intuition' that qualifies a structural architecture designer. «During the design phase of light structures, in particular of tensile structures, it is essential to define a structural system that directs the forces according to the desired directions, bringing them to the ground to obtain the maximum performance of the materials, the minimum clutter of intermediate space and the maximum aesthetic result» (Majowiecki, 1994, p. 45).

Notes

1) The small-sized transformable structures: mobile, removable and transportable, are used temporarily for various occasions: exhibition stands, emergency tents or military tents. Conversely, convertible roofs for large areas are usually permanent and fixed, with the possibility of being removed without damaging the existing buildings.

2) This class includes most of the large convertible roofs made before the 1970s. The experimentation on the conversion mechanisms was still ongoing, the opening and closing times exceeded 30 minutes. The reversibility of the structure was therefore limited to installation and uninstallation moments only, fulfilling only a criterion of constructive reversibility.

3) The oldest artefact was found in Moldova and dates back to 44,000 BC.

4) The 'yurt' tent is an evolution of the 'kurke', circular Neolithic tents with umbrella structure, consisting of rods and tarpaulins on a conoidal shape. The 'yurt' appears about two thousand years ago and takes the forms of the latter, with a circular base, cylindrical development and conoidal cover, also in wood and sheets. The passage from one camp to another involves the disassembly and transport of the tents. These can be dismantled in less than an hour, then the rod racks are folded into bundles and loaded onto the back of pack animals. Upon arrival in the new camp, the tents are reassembled with a time of about one hour each.

5) Other inventions are attributable to Leonardo da Vinci, such as a large umbrella, a pantograph system for lifting weights, the design of a bridge consisting of the repetition of a single modular piece, and a primitive aeroplane.

6) The 4D House consisted of a model consisting of two load-bearing hexagons suspended rather freely from a central tripod pylon. Based on the then-current price of the auto industry, he estimated that such a fully equipped house could be mass-produced for $ 4,800.

7) In the revised version of 1951, the sphere of the Dymaxion Air-Ocean Map was divided by an icosahedron grid, with identical triangular faces, rather than cuboctahedron.

References

Capasso, A. (ed.) (1993), *Le tensostrutture a membrana per l'architettura*, Maggioli, Santarcangelo di Romagna (RM).

Eaton, L. K. (1962), "The Turning Point of Building: Structure and Design by Konrad Wachsmann", in *Journal of the Society of Architectural Historians*, vol. 21, n. 3, p. 146. [Online] Available at: www.jstor.org/stable/988060 [Accessed 12 November 2019].

Escrig, F. (1996), "General survey of deployability in architecture", in Brebbia, C. A. and Escrig,

F. P. (eds), *Mobile and Rapidly Assembled Structures II*, vol. 24, WIT Press, Ashurst (UK), pp. 3-22. [Online] Available at: www.witpress.com/elibrary/wit-transactions-on-the-built-environment/24 [Accessed 12 November 2019].

Forster, B., Mollaert, M., Associazione TensiNet. and Zanelli, A. (eds) (2007)*, Progettare con le membrane*, Maggioli editore, Santarcangelo di Romagna (RM).

Gorman, M. J. (2005), *Buckminster Fuller – Architettura in movimento,* Skira, Ginevra.

Majowiecki M. (1994), *Tensostrutture – Progetto e verifica*, Consorzio Crea, Massa.

Marks, R. W. (1960), *The Dymaxion World of Buckminster Fuller,* Reinhold Publishing Corporation, New York.

Nardi, G. (1986)*, Le nuove radici antiche – Saggio sulla questione delle tecniche esecutive in architettura,* FrancoAngeli, Milano.

Osayimwese, I. (2009), "Konrad Wachsmann: Prefab Pioneer"*,* in *Dwell – The Prefab Issue – Real Homes for Real People*, pp. 98-102. [Online] Available at: www.academia.edu/8001642/Konrad_Wachsmann_Prefab_Pioneer [Accessed 15 November 2019].

Otto, F. (2004), "Finding form", in Forster, B. and Mollaert, M., *European Design Guide for Tensile Surface Structures*, Tensinet Edition, Brussel, pp. 6-7.

Rodríguez, L. F. and Monrabal, C. S. (2011), "El General Panel System de Konrad Wachsmann y Walter Gropius, 1941", in Huerta, S., Gil, I., Garcia, S. and Tain, M. (eds), *Actas del Séptimo Congreso Nacional de Historia de la Construcción, Santiago 26-29 Octubre,* Instituto Juan de Herrera, Madrid, pp. 375-385. [Online] Available at: www.researchgate.net/publication/330937950_El_General_Panel_System_de_Konrad_Wachsmann_y_Walter_Gropius [Accessed 15 November 2019].

Schock, H. J. (2001), *Atlante delle tensostrutture,* UTET, Torino.

Wachsmann, K. (1992), *Holzhausbau – Costruzioni in legno tecnica e forma* [or. ed. *Holzhausbau – Technik und Gestaltung*, 1930], Guerini e Associati Editore, Milano.

Zanelli, A. (2003), *Trasportabile/trasformabile – Idee e tecniche per architetture in movimento,* Clup, Milano.