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In Emilio Pérez Piñero's work, invention takes place in the process of the architectural project through an extraordinary understanding of geometry and algebra and an exceptional ability for abstraction.

Emilio Pérez Piñero: invention through abstraction

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Nothing could be more fitting than the prodigy designer of an extraordinary piece of architecture – the folding reticulated structure[1] to cover an unprecedented 8,000 m^2 of exhibition floor space – standing on his folded structure in the forecourt of the Nuevos Ministerios in Mdrid, where an exhibition celebrating twenty-five years of peace, and Spain's achievements diring that period, took place *[1]*.[2]

Emilio Pérez Piñero (1935–1972) standing atop his achievement should not be judged by the fact that he looks triumphant in this setting. He was not in any way linked to the regime. It is impossible to know the deepest political thoughts of this man of few words. However, that bundle of metal rods on which he is standing is a different matter. Here, at least, there is no room for inaccurate interpretations as to the design for the *25 Years of Peace Exhibition* (a travelling exhibition twenty-five years after the Spanish Civil War) that Pérez Piñero produced. It demonstrates simplicity and precision: there is nothing superfluous in this structure. It was a brilliant idea executed to perfection by a firm specialising in aeronautical engineering and precision industrial work.[3]

1 Emilio Pérez Piñero standing on top of one of the 'bundles', which, retracted would for easy transportation, would cover a large surface area.

1

Why Pérez Pérez Piñero today?

The development of the work of some of the most inspiring architects and engineers after their death depends primarily on the depth of understanding among their followers. The death of Emilio Pérez Piñero was sudden, tragic, and above all, unexpected. He not only left his work unfinished, but his friends, colleagues, and collaborators did not have a chance to get ready for continuing the work. His legacy shows a remarkable ability to resolve design problems while building models of his prototypes. It reveals an incredible three-dimensional agility in the use of geometry that led to a truly innovative way to develop tubular structures. Above all his work constitutes true invention.

Far from being an architect lost in the past, the work of Pérez Piñero has continued to attract a great deal of attention from scholars in various fields. Pérez Piñero's impact during his lifetime was felt mostly in Spain and only started to be known abroad after his UIA Competition success.[4] It is important to be aware that Spain was at that time very much ignored on the world stage. Economically, it was trailing behind the leading countries in Europe. The US had excluded Spain from the Marshall Plan of 1948, making Spain's economic recovery painfully slow. Politically, Western democracies ignored Franco's regime, which was known as a dictatorship and therefore not seen as attractive. Culturally, the Spanish Civil War had been a deep disruption in cultural life. The first two decades after the Civil War could be described as mending a tear. The work of Pérez Piñero caught the world by surprise, not only because of its originality but also because nothing new in technology was expected to come from Spain. Towards the end of his life, Pérez Piñero's work was becoming known, as evidenced by the number of prizes he won in those few years. His fame continued to grow for a few years after his death but was limited to Candela's support and NASA's interest.[5] His work, however, has not been developed as much as that of other inventors of his calibre. The development of folding structures has not had any significant notoriety because the concerns of the world of construction have been focusing on other fields. However, Pérez Piñero's work did alert the rest of the world to the technological innovations that were taking place in Spain.

Most of the existing scholarship on Pérez Piñero centres on the application of the latest software,[6] although some scholars, however, do compare his work with the work of his contemporaries and demonstrate the influence Emilio Pérez Piñero had

on them.[7] Manuel Alejandro Ródenas-López and others confirm Pérez Piñero's genius, explaining that, without the aid of software, he was able to optimise the use of material, as well as the efficiency of geometry.[8] More recent studies use the latest software and computational analysis to quantify numerically what Pérez Piñero had visualised in his mind. These recent findings are relevant for us because they prove that, while nowadays we are able to quantify these limits accurately, Pérez Piñero was not only fully aware of them, but indeed used them geometrically to seek – and achieve – the position of equilibrium in deployable folding structures. Also relevant in excellent studies on, for example, the eccentricity of the rods by Adolfo Pérez-Egea and others are not so much the empirical quantitative results but the fact that the eccentricity will always be there because it is implicit in the very nature of the node.[9] (When two rods are linked by a bolt and washer through the middle of them, these rods can rotate freely 360 degrees in one plane, but when three or more rods are linked by a node such as the one shown in figure *[1]*, one can see that the angle of rotation of each rod is reduced. In other words, the rods can rotate but only a limited amount. That is to say the mechanism has reached its extension limit.) Strictly in terms of invention, the relevance of eccentricity is that Pérez Piñero sees in it the capability of controlling the geometry of folding structure.[10]

Some scholars of Pérez Pinero's work, such as Jose Calvo Lopez and Juan Pedro Sanz-Alarcon,[11] have compared it with the work of other great architects and engineers of his time. They claim a podium for Pérez Piñero among the great designers of his decade for his astonishing vision. Federico Luis del Blanco Garcia in particular – looking at Pérez Piñero's relationship with Felix Candela, his friend and mentor – offers a valuable contribution as he comes to prove, tangentially and by implication, that Pérez Piñero's work is truly original because he ratifies that Pérez Piñero's work is a break: both from what came before him and what has come after him and not a development of an existing technology.[12]

In summary, these recent studies confirm the importance of invention of Pérez Piñero.

However, a great deal of the work carried out by scholars of Pérez Piñero to this day has consisted in developing the detail, that is, his problem solving, by using computational and algorithmic tools that did not exist in his time. A good number of others have continued his innovative work by the physical application of what he started and continuing his innovation (doing the same thing but in an improved way).[13] It is important therefore to look at the legacy of the work of architects such as Pérez Piñero who have become landmarks in the history of architecture, from the point of view of whether their work can truly be called invention and not just innovation, development or application of an idea, or indeed simply, problem solving. Looking at invention in the light of the work of Emilio Pérez Piñero leads not only to a deeper understanding of the significance of the potential uses of folding structures but more importantly to the discovery of other aspects that will constitute inventions in themselves.

Invention

While invention and innovation seem to be almost interchangeable, and often mistakenly included under the same heading in common speech, distinctions are only articulated when it is absolutely necessary in present day culture, which is, above all, pragmatic. Distinctions are vital in order to avoid misunderstandings. Invention, from the Latin *in-venire*, meaning finding, discovering, is in engineering, commonly reduced to producing a device used in order to profit from some natural phenomena. In art, however, to talk about invention is rather inappropriate, whereas in architecture there is a middle ground where both engineering and art meet. Invention in architecture lives where the world of the immaterial, the thought, the concept, the idea meets the material, the tectonic, the construction. Innovation is not invention. Innovation is doing the same thing in a new and better, or improved, way whereas invention refers to doing something never done before. Problem solving is neither invention nor innovation but a stage through which all designs must pass in their course of becoming the final product. In engineering and architecture problem solving can be the clearest manifestation of clarity of thinking, the skilled application of the power of the discerning mind or the orderly application of a disciplined methodology, and for this reason it may appear very close to invention or innovation, but a lack of distinction here too would lead to confusion.

As for originality, what is invented is obviously new and thus it is often confused in common language with originality. Something new is often considered original. But this confusion leads to more confusion when it is set against singularity. According to its etymology, something is original the closer it is to its origin. In other words, what is original is what is contained in the nature of things. It is true that many inventions, especially those that have come about as a result of the discovery – or more precisely the harnessing of a physical phenomenon hitherto unknown to man – have dealt with the nature of things. An invention gains in value the closer it is to its origin, although a design may be singular and even unique but not on account of its originality. Often invention follows on from the discovery of a physical phenomenon. In the case of Emilio Pérez Piñero, the two are so intimately intertwined that it is difficult to separate them. When looking at the whole of his work, invention is most clearly present in the expanding reticulated structures.

Finally, invention, innovation, and problem solving can be happily placed under the umbrella of creativity, but creativity is not creation. Paraphrasing Álvaro Siza, one could say that 'the architect does not create anything but transforms something.' 'Architects don't invent; they transform.'[14] The distinction seems still valid especially when we

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consider that to design is the materialisation of the idea, the concept, or even the feeling. Nobody these days would claim creation *ex nihilo*. Creativity is the capacity to foresee what can be, ahead of any transformation. The form is what is changed in the transformation, understood as the internal form, not just the shape.

Creativity is expressed in many ways. Invention, however, does not occur that frequently in the work of the architect. It requires a very specific set of qualities of mind, skills, and also experience to make the discoveries that bring about invention. The work of Emilio Pérez Piñero is a very good example of how invention can take place in the conceptual stages of the process of the architectural project through abstraction. The purpose of including here some biographical details is to show how the required conditions for invention met in mind of Emilio Pérez Piñero. Likewise, descriptions of the vicissitudes of his projects are provided here to help show the conditions under which his inventions occurred in the understanding of his design as opposed to the material execution of the concept that his privileged mind bore.

Emilio Pérez Piñero's background

Although Emilio Pérez Piñero was born in Valencia (on 27 August 1935), his family moved, when he was still a child, back to the small town of Calasparra in the province of Murcia, Eastern Spain, from where the family came. His father, Antonio Pérez Ruiz, was an army engineer in the Republican Army, posted in Valencia when Pérez Piñero was born. Pérez Piñero was not yet a year old when the Spanish Civil War threw the country into the bloodiest fratricidal war that the country had ever seen. At the end of the war Pérez Piñero's father was in prison and the child never saw his father until he was eight years old. During that period, he lived with his mother in his maternal grandparent's house, with his brother José María, who was three years his senior, and his mother's relations.

In his early infancy, the family was torn by distance and separation. To the absence of the father, one has to add the discrimination due to the knowledge that his father was in prison and so, at the age of eight, Pérez Piñero had not been taught to read or write. When his father came out of prison, he took the education of his son very much as his duty. He would teach him the sciences, and a friend of the family, a schoolteacher by profession, Ricardo López, would teach him the humanities. Among the army engineers of that time there were the best mathematicians and physicists in the country.[15] A teacher like this would have a great impact on Pérez Piñero. In addition to his natural gifts, which were undeniable, he acquired an understanding of mathematics and physics made-to-measure by an expert who cared. In those first eight years of his life without formal education, he spent a great deal of his time making things, objects, and his own toys.[16] Whether accidentally or not, his creativity was channelled through to the acquisition of a dexterity with his hands and the ability to form objects from models in his head. He was of above average intelligence, very diligent and very active.

At the age of thirteen Pérez Piñero was sent to school (The Cervantes School in Caravaca de la Cruz). At first he did not have an easy time, and he was always at the bottom of the class. After the first year, he got the top mark in all eleven subjects. He had a special ability for mathematics, physics, and drawing and he was undeniably interested in everything related to the working of things in general, in the world that surrounded him. At the end of his secondary education, he had made up his mind to become a merchant seaman because it was quite a short course but when his father suggested to him to go to Madrid to study architecture he readily agreed.

Having a caring father with a great knowledge of mathematics and the sciences prepared the ground for invention to be possible in the mind of Emilio Pérez Piñero. In emphasising his education and his childhood experiences the intention is to show he was clearly precocious child and youngster, who was making use of his skills and talents in a selective way. It is not uncommon, even in ordinary speech, to hear statements that imply a selective perception. The subject perceives reality according to very specific parameters, forged by age, experience, learning, etc. Undoubtedly Pérez Piñero saw the world around him with a very special selective perception from an early age, shown in the way he used his time making his own toys, that according to his family all worked. In this sense they were more than toys. They were artefacts that performed; genuine gadgets, the fruit of his three-dimensional mind and the skill of his hands.[17]

Perhaps, so as not to make this comparison too lengthy, it would be good to go directly to the kernel of the issue. As Juan Antonio Arnuncio Pastor has put it, 'an intelligent gaze allows us to extract from our surroundings, the raw materials with which to construct an aesthetic thought.'[18] It is quite beautiful to see that Emilio Pérez Piñero, working first on the artefact, and later on in his life, on the mechanism, finds the conditions under which the mechanism ceases to be dynamic and becomes static and then, turns his mind on how to make it remain static. With this in mind it is quite moving to read his letters home, particularly from London where he went to receive the UIA Award: one can appreciate that he is at another level, even from his teachers.[19]

University years

Regarding his years at university, two periods can be distinguished: before and after 1961. Between 1952 and 1957 Pérez Piñero prepared his entry into ETSAM (Escuela Técnica Superior de Arquitectura Madrid) the architecture school in Madrid by reading Sciences at the Faculty of Sciences of the University of Madrid. A level of science comparable to a first degree was required, what today we would call a BSc.

In these years, some of his contemporaries considered him introverted and shy.[20] However, perhaps this apparent shyness may have been no more than the natural result of being already a married man, for in the course of his first year in the

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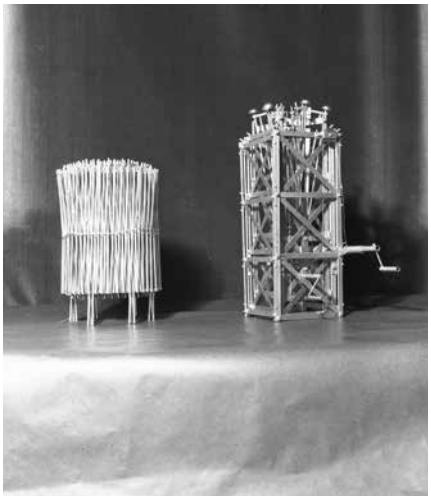

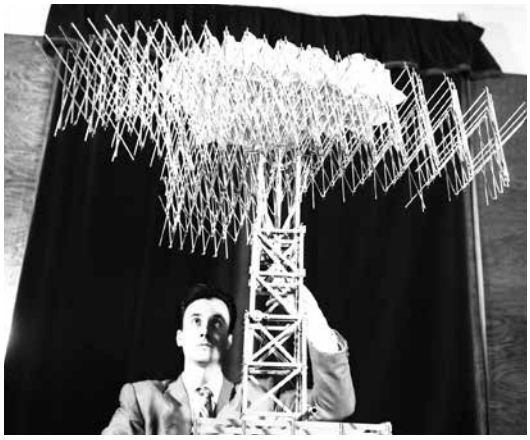

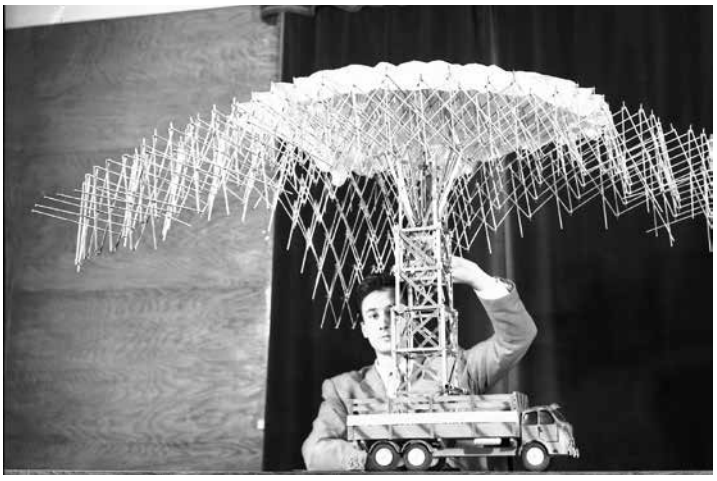

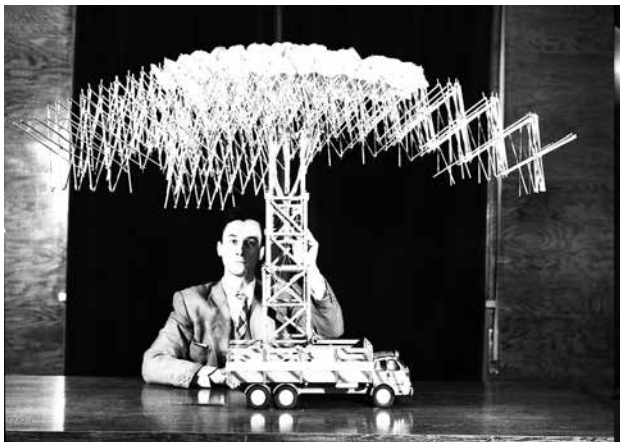

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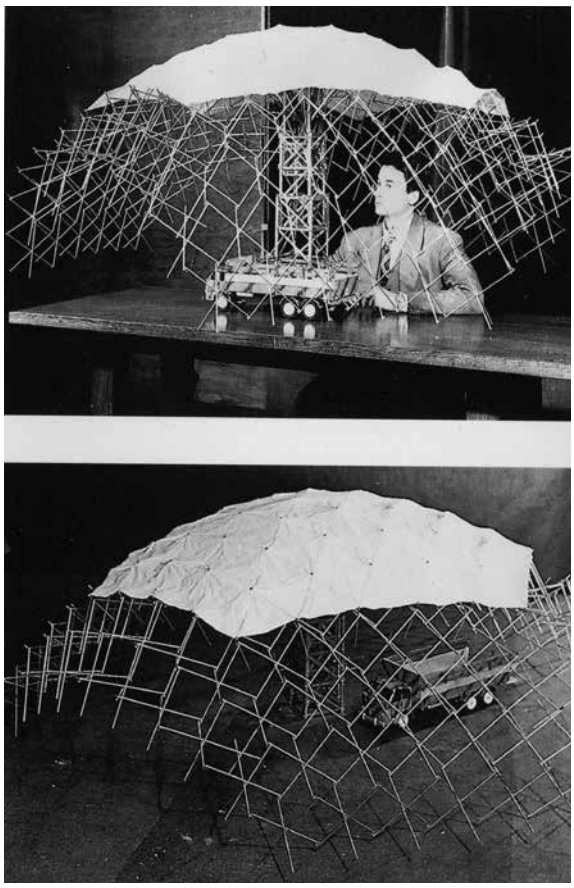

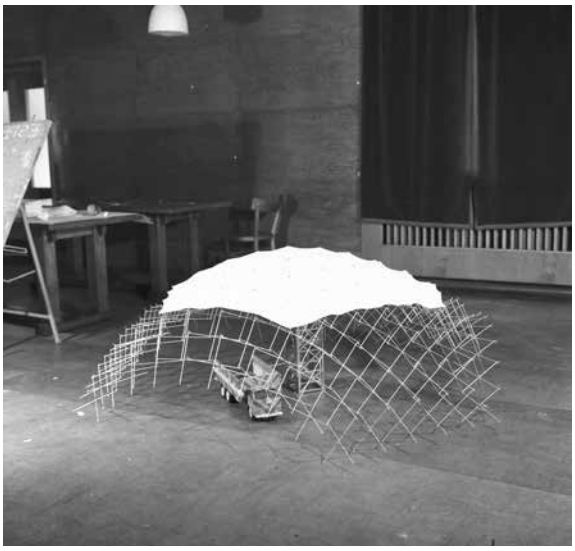

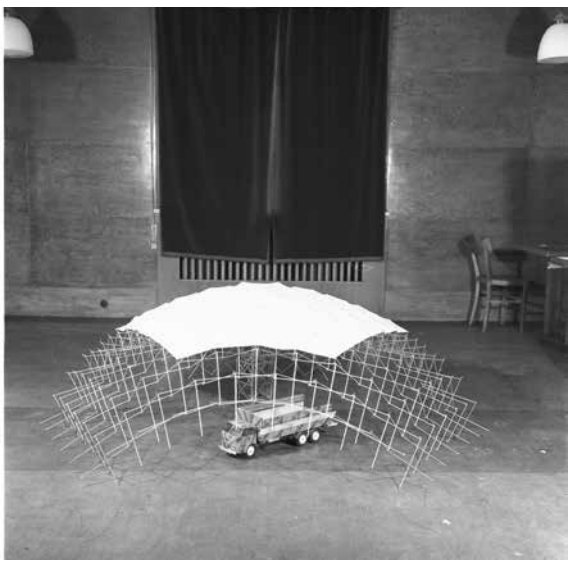

2 The School of Madrid decided to have a competition and Pérez Piñero submitted his Travelling Theatre (Teatro Ambulante). He was selected to represent the School at the VI UIA Congress. These are stills from the presentation.

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school of architecture he married on 2 October 1956, Consuelo Belda Aroca, and from then onwards, social life and his interests were with his wife rather than with his classmates.[21]

In his first year in the Faculty of Science, he obtained the highest mark in Mathematical Analysis: At ETSAM, he took all the courses, ranging from Geometry, Strength in Materials, Stability, but above all he shone in a subject then called Construction where the study of metallic reticulated structures had received first attention with the work of Zygmund Stanislaw Makowski,[22] Richard Buckminster Fuller and others. That opened his eyes to new ways that he was going to explore so fruitfully.

The organising committee of the UIA congress arranged that, within the programme of the 1961 Congress in London, there should be presentations of work from the schools of architecture of the countries taking part in the VI Congress.

ETSAM decided to have a competition and Pérez Piñero submitted his Travelling Theatre (Teatro Ambulante). His project was truly outstanding, and he was selected to represent ETSAM at the VI UIA Congress together with the project of Ricardo Urgoiti, the runner up in the school competition. The two of them travelled together to present their works.[23] Pérez Piñero's competition project was a resounding success. His project consisted of an ingenious reticulated structure of thin tubes linked by a remarkable joint that allowed the structure to extend into a full dome from a compact bunch of thin rods fitted to a telescopic crane sitting on the back of a lorry *[2]*. The crane would lift the bundle of rods to a prescribed height, the bundle ties would be released, and the reticulated structure would then extend into a dome with the sheet covering being stretched over the structure; the crane would then be detached from the self-supporting dome, retracted back on to the back of the lorry, which would finally come out from under the dome leaving the theatre shell deployed. A variation of the same extending and contracting reticulated structure made of the same metal rods linked by a variation of the same incredible three-dimensional articulated node made up the entire seating.

During the time Pérez Piñero spent in London, he presented his project several times. Articles on his work appeared in magazines outside Spain, such as in *Architects' Journal* and *Architectural Design* in the United Kingdom, as well as in Spain (several in *Arquitectura*), [24] and it was exhibited in Germany. The reason for this attention was clear. Firstly, because a special prize and honourable mention, never given to any project before, was awarded to his project, as well as other international prizes, such as the Gold Medal at the 3rd Biennale in Brazil, in São Paulo, and secondly, because there were great experts in the field among the members of the adjudication panel, such as Félix Candela, Richard Buckminster Fuller, and Ove Arup. Candela became his great friend and mentor. In his letters home from London, he clearly stated that the only one who cared for him was his fellow countryman Félix Candela, who was by then living in exile in Mexico. This friendship meant that Félix Candela saw it his duty to make Pérez Piñero known on the American continent, where he already had made a name for himself. Until his death, Pérez Piñero always had the support and ready help of Candela.[25] Pérez Piñero's relationship with Richard Buckminster Fuller was very cordial but not very communicative because they did not speak each other's language. They met several times in the course of those conference days and the young student made such a very positive impression on Fuller that fourteen years later, and four years after Pérez Piñero's death, he said in a private conversation that he considered Emilio Pérez Piñero a genius.[26]

When Pérez Piñero came back from London he had not finished his degree course. He had the fifth year and the Proyecto de fin de Carrera, which was the equivalent to The End of Career Thesis Project or Degree Project, still to finish, and he managed to combine his school commitments with the many offers that the London success had brought into his life. He finished his studies brilliantly obtaining the Extraordinary Prize Anibal Alvarez on 9 July 1962. His Degree Project was a Shrine to Our Lady of the Flight into Egypt, which is the Patron Saint of Architects in Spain.

ETSAM had produced before him a generation of prominent architects, Alejandro de la Sota, Francisco Javier Saenz de Oiza, Antonio Fernandez Alba, Javier Carvajal, that were all, on average, at least ten years older than him. The Madrid School remained very much at the cutting edge, with, among others, José Miguel de Prada Pool's research on Pneumatic Structures.[27] Fernando Higueras, although he graduated in 1959, may have known Pérez Piñero. Rafael Moneo was a student in the school of Madrid at the same time as Pérez Piñero, although Moneo graduated a year earlier. Immediately after graduating, Moneo went to work in Utzon's office in 1961 and 1962 and then he became a Rome Scholar (1963), so Moneo was abroad when Pérez Piñero was awarded the UIA prize in London.

It is important to consider that there were just two schools of architecture in Spain at the time and therefore the selection procedure was very hard, he was surrounded by very competent peers[28] and also, that his great success in the school, was in dealing with more abstract subjects: his were not projects about maximising the use of floor space in the layouts for social housing or the study of role of vernacular origins in contemporary architecture, which were attractive enough subjects at the time. His were clearly more abstract speculations in which the three-dimensional vision was an essential part of its conception.[29]

Deployable structures

Retractable, folding, demountable, or deployable are words used to describe Emilio Pérez Piñero's structures. His contribution in this field constitutes one of the most important landmarks in the twentieth-century lightweight architecture. Although there have been some very interesting studies, doctoral theses, and articles about him it is remarkable, considering the quality of Emilio Pérez Piñero's inventiveness, how few there have been that can be said to have continued his work, indeed, to have pushed it forward.

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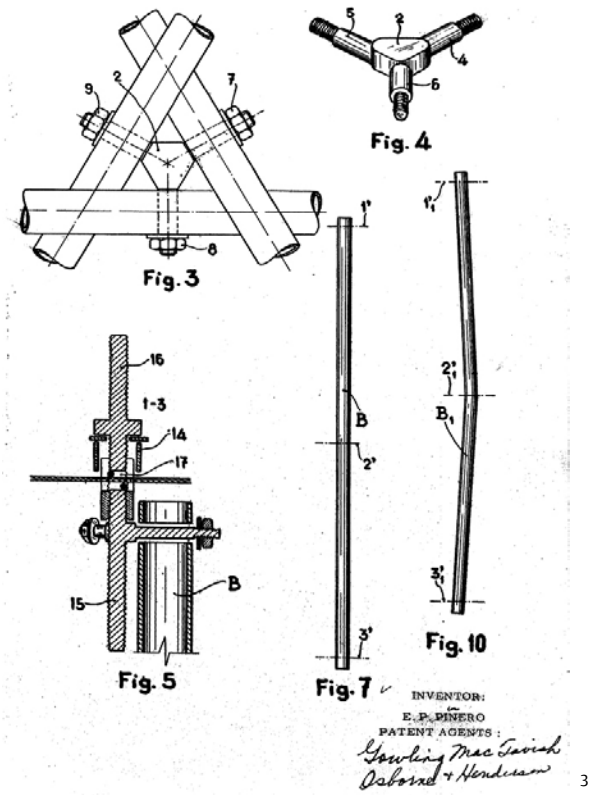
The idea of a deployable structure has existed for centuries, mostly due to the nomadic nature and habits of many of the civilisations that have come before us. The need for something light to be able to be transported together with the rest of the baggage forced humans to seek materials and designs that would give an adequate response to this need. The kit of parts is a common denominator to most of the examples. The larger elements are limited to what can be transported with relative ease.[30] Over the span of centuries successive generations the designs are developed and improved.

The coupling of jointing of elements become more and more sophisticated in design but simpler in their use and application in order to make their assembly and disassembly easier and faster. The integrated system, whereby not all the parts of the kit need to be attached or detached in the process of assembly but remain permanently attached to one another, together with steel replacing timber, give rise to the mechanisms, which we see nowadays and often associate with machines rather than structures. The umbrella is a folding structure, which has developed very little since it was first invented. Many centuries later, it started to be manufactured in relatively large numbers and eventually commercialised. But even after it became a commodity in the last two hundred years there has been very little development, probably because it achieved its usefulness very soon after it was first made, and its use has not substantially changed, nor its original brief extended.

The reticulated structure comes of age when the designer starts looking at its manufacture and performance in terms of a collection of elements that can transfer loads in any direction.[31] Accurate geometry is the key point of an efficient answer. The geodesic breakdown of the sphere is the classic example, whereby a sphere can be reduced to rods and nodes, which work both in tension and in compression. In the twentieth century, the advent of the reticulated structures marks the moment of coincidence of, on the one side, industrial advancements in the production of lighter and stronger metal alloys and, on the other, great developments in structural engineering design to reduce the weight of the structure and improve its resistance to loads and stresses. Coupled with a good understanding of geometry, the industrialised version of the reticulated structure was bound to happen and quickly gain its place in the world of light roofs to cover large spans.[32] The methods of fabrication and procurement did not lag behind and soon in the decade of the 1960s there was a plethora of patents of systems consisting of nodes and rods that could be assembled relatively quickly.

By the time Pérez Piñero entered ETSAM, there were already a number of Spanish patents obtained by firms specialising in reticulated structures, both planar, typically space frames, and curved. The lightweight nature of the product meant that the state of the industrial development in Spain could cope very well with this kind of manufacture. Architects and engineers were well versed in the



3 Copy of the application for a patent of the design for the node to link three rods.

capabilities these methods offered. In spite of all that, the work of Emilio Pérez Piñero can be said to be a revolution because there was no prehistory to make us suspect or indeed anticipate his solutions as coming from the work of any predecessor. They are his invention; the fruit of his singular and original approach to design that are undoubtedly a stroke of genius.

A revolution in the deployable structures

Emilio Pérez Piñero's contribution to reticulated structures and his fascinating folding structures was possible because he was able not only to conceive in his mind the finished form but also the way to go from the abstract geometry, without weight or mass, to the built form completely materialised. The novelty of work is that he does not separate the final structure from the designing and making progress. In his work, it is not right to think of a structure and then try to make it fold. This is not how he worked. When we enter Emilio Pérez Piñero's world, the sequence is understood as belonging to a stage of the development of the design.

In his work on folding structures there are no reticulated structures, per se, at the beginning. There are rods tied together that can move in relation to each other, according to a predetermined motion. He designs that motion. That is to say, the rods are tied to each other in a prescribed manner. Rods are linked to each other at the ends or at the middle. There can be an unlimited number of rods or rods tied together by nodes at each end and at the middle, nodes that allow the rods to gyrate, move, or turn *[3]*.

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By means of these movements the whole set of rods can be extended or retracted into a bundle. It would therefore be more accurate to speak about mechanisms rather than structures. Movement is predetermined and limited. The rods are not free to move in a random direction but in a carefully designed and predetermined way.

The knowledge of these structural systems was not achieved by deduction, that is, by one thought leading to another. Simultaneity is a difficult concept to express when dealing with a train of thought. His extraordinary mind, however, was capable of seeing all at the same time. This simultaneity is crucial for the right understanding of Emilio Pérez Piñero's work. The reticulated form and the folding mechanism are born and develop together as equals: one does not serve the other. The rods or bars are linked to each other by the node, an essential part of his breakthrough, because the node typifies the simultaneity just referred to above.

Pérez Piñero's node is the offspring of both the folding mechanism and the reticulated form. In conventional reticulated structures, the nodes keep the ends of the rods captive, whereas this is not the case with Pérez Piñero's node. The distinction between the conventional node, whose mission is to keep the ends of the rods captive and Pérez Piñero's node allowing a predetermined motion is of paramount importance for the correct understanding of his folding structures.

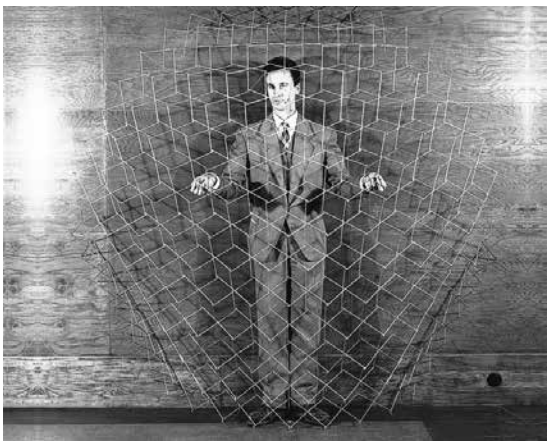
Pérez Piñero designed a number of families of nodes. What defines these nodes is that they link the rods together, of course while also allowing them to move or gyrate, rotate in a particular way. The nodes are therefore what make the rod assembly capable of folding and transforming its shape. Again, unlike all other nodes, which are designed to accommodate a number of rods and angles of incidence, Pérez Piñero conceives the node and develops it together with the reticulated mechanism. That is why, among other characteristics, his structures are as light as they can be. His extraordinary capacity for abstraction led him to admit nothing superfluous in his work.

Pérez Piñero's work, especially in folding structures, is an eloquent example of abstraction, where the simultaneity of conception and development respond to both the inspiration and execution at once. His perception is both three-dimensional and causal. Because the limits of the movement of each rod are worked out three-dimensionally, geometry in his work is both the result and the intention. In his mind the end of the rods are points in space that keep the relationship between them unaltered throughout the course of the movement: the movement of these sets points is a true mathematical translation of their coordinates, in the sense of algebraic topology.

From mechanism to structure

Pérez Piñero's folding mechanisms were planar or curved. If the middle link or node is in a point equidistant from the end ones, we have a planar structure, whereas if the point is nearer one end, we have a curved structure. It is as simple and beautiful as this. If the mechanism is planar, it needs to be opened by pulling from two opposite ends *[4]*. The models of planar mechanisms were all provided with castors attached to strategically selected nodes to facilitate this action. In the case of curved mechanisms, by hanging the mechanism from specific points or nodes it will open by the very self-weight. In the case of full-scale models, cranes, scaffolding towers, or helicopters were needed to lift up the entire mechanism and hold it by those carefully chosen points. The self-weight as a means to 'activate' the mechanism is an aspect that Emilio Pérez Piñero developed only partially since he was working his ideas through when the opportunity arose in each project (usually when commissions became a reality). His research was not theoretical; it was the consequence of solving the problems in each situation he faced.

Pérez Piñero's designed the unfolding of the curved structure by means of a telescopic tower on the back of a lorry in the 1961 Ambulant Theatre Project. He did the same with the planar ones like the *25 Years of Peace Exhibition* Pavilions.[33] For the curved ones, in particular, he also designed the scaffold tower and the helicopter versions. In all cases, the reticular mechanism is allowed to unfold until it is fully expanded and then it is 'locked' in position, at which point the mechanism becomes a static structure. It is very interesting to see the ways in which he makes the mechanism static. In all cases the expanded position is the one of maximum efficiency, both from the geometry point of view (enclosing the largest surface and achieving the largest spans) as well as from the structural point of view (reducing the length and number of members working in tension). Pérez Piñero designed solutions where the 'locking' elements were rods or bars and used cables to lock the mechanism 'completing' the geometry. Once the folding mechanism's geometry is completed, and 'locked',



4 His folding mechanisms were planar or curved. If the middle link or node is in a point equidistant from the end ones, we have a planar structure, whereas if the point is nearer one end, we have a curved structure. It is as simple and beautiful as this. If the mechanism is planar, it needs to be opened by pulling from two opposite ends.

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it ceases to be a dynamic mechanism and becomes a static structure. The process has the beauty of musical harmony.[34]

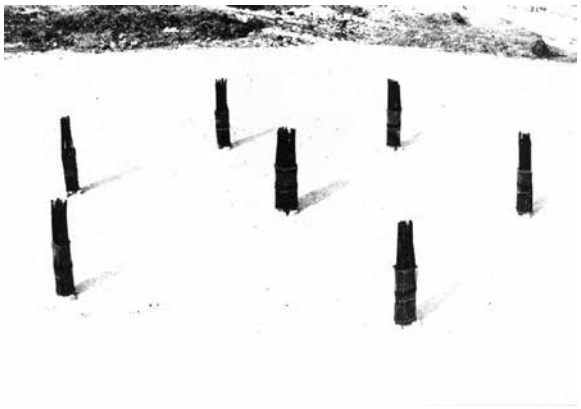
It is impossible to arrive at Pérez Piñero's folding structures by thinking first of a shape, be it a sphere, a hyperbolic paraboloid, a ruled surface, etc., or any other curved surface and then to try to make it fold. Pérez Piñero's way was to think first of the mechanism. The demands of the project are the ones that determine the shape.

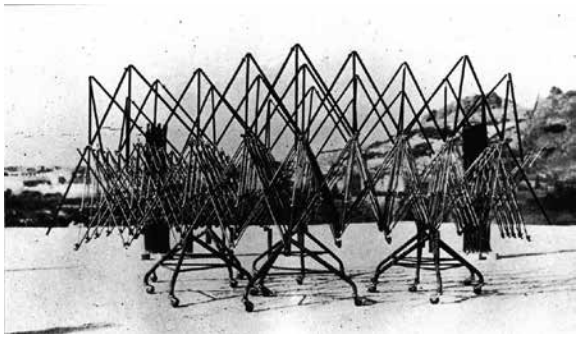
Strictly speaking while the mechanism is still moving it is dynamic in nature and as such should not be called a structure because a structure, by definition should be stable. The process of transforming a mechanism into a structure is the invention that Pérez Piñero offered the world.

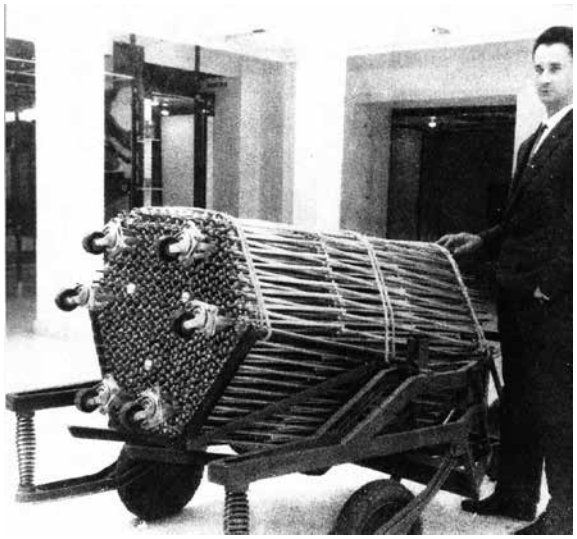
Here again, it would be appropriate to point out that the origin of the invention occurs by abstraction, not by deduction and certainly not by trial and error. In this case, by seeing that which had not been seen before, which is a prerequisite for invention to take place. Emilio Pérez Piñero's works have been, from the very beginning a challenge to all architects and engineers. The 1961 Ambulant Theatre Competition Project idea is still fresh today.[35] In 1968 he worked on the design and construction of reticulated folding dome for large spans in seven sections *[5]*. In those critical years when he was travelling a great deal, starting his business, and also starting his teaching duties, he was nevertheless able to develop a project that answered all the challenges he had faced at that time in one go. He was resolving the most difficult aspects of sectional assembly of reticulated structures and his folding mechanisms optimising their application and moving up into the large spans category.

The assembly of reticulated domes always forces the designer to confront the fact that there is certain distortion of the dome due to the self-weight of the structure. If the structure has been made lighter by reducing the sections, the ability to take loads and stresses without distortion during the process of assembly is also reduced. If the assembly is top-down the major circle is distorted to the point that the last ring does not close. If the assembly is bottom-up, then the last piece – which in the case of the geodesic breakdown is usually a pentagon – will not fit in. Pérez Piñero fully recognised the difficulties surrounding the assembly of reticulated domes. When he tackled the 1968 design and construction of the reticulated folding dome for large spans in seven sections, he approached the assembly as a designer of folding structures designer would, but the folding mechanism 'achieves its static position' at the moment of assembly with the neighbouring sections.

This design strategy for the assembly of seven pieces shows Pérez Piñero's maturity as a structural designer and his understanding of the way in which the form and the function meet. In this case the function of folding has met the division of the geodesic breakdown of the sphere in the six sections that converge in the closing cap or seventh. And vice versa, each folding section meets its neighbour precisely along the lines of the load paths reducing the stresses to a minimum. Invention is in most cases seeing what was hitherto hidden, seeing the principle or the concept and not the detailed resolution. Detailed resolution is more often than not described as problem solving quite distinct from invention. There is, however, a predictable search path in exploring the options, which will resolve the problems of execution. The path from the concept to the detail needs instead to be understood as where inventors express their brilliance in the simplicity of







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5a–c In 1968 he worked on the design and construction of reticulated folding dome for large spans in seven sections.

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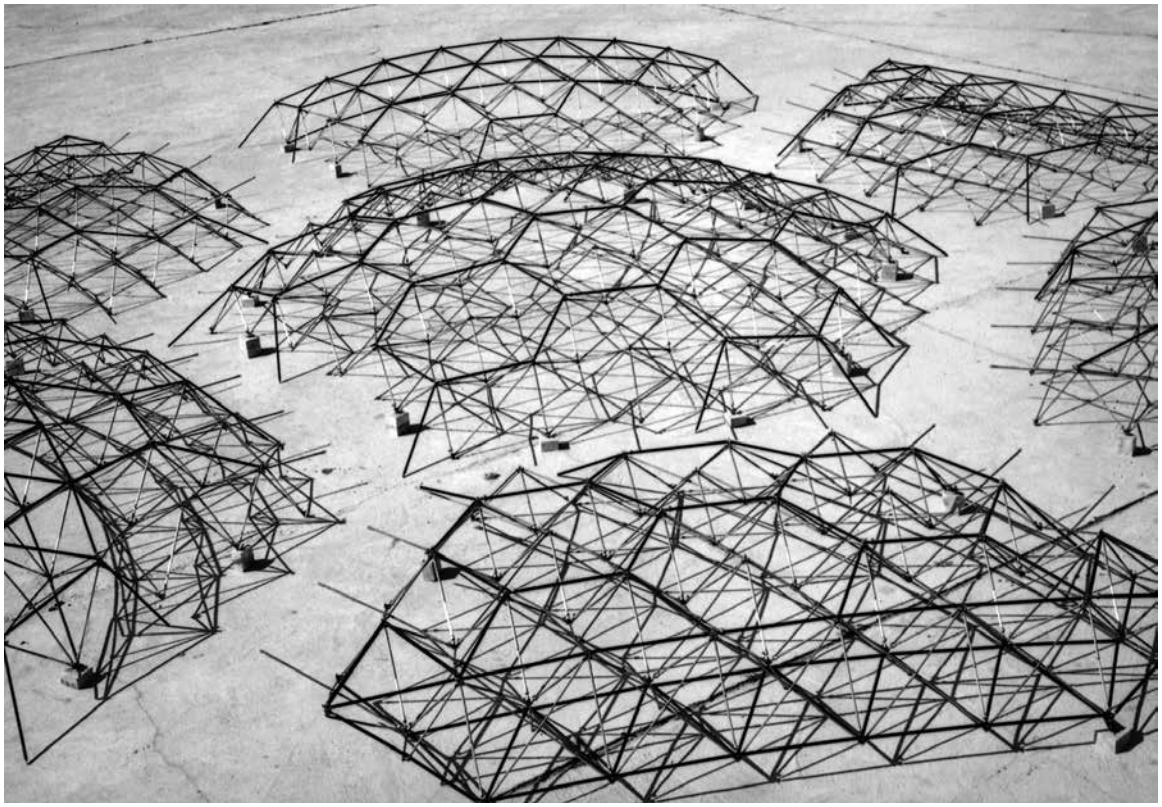

6a–d The dome in seven sections and the 25 Years of Peace Exhibition Pavilion are two designs in which there is nothing superfluous.

6

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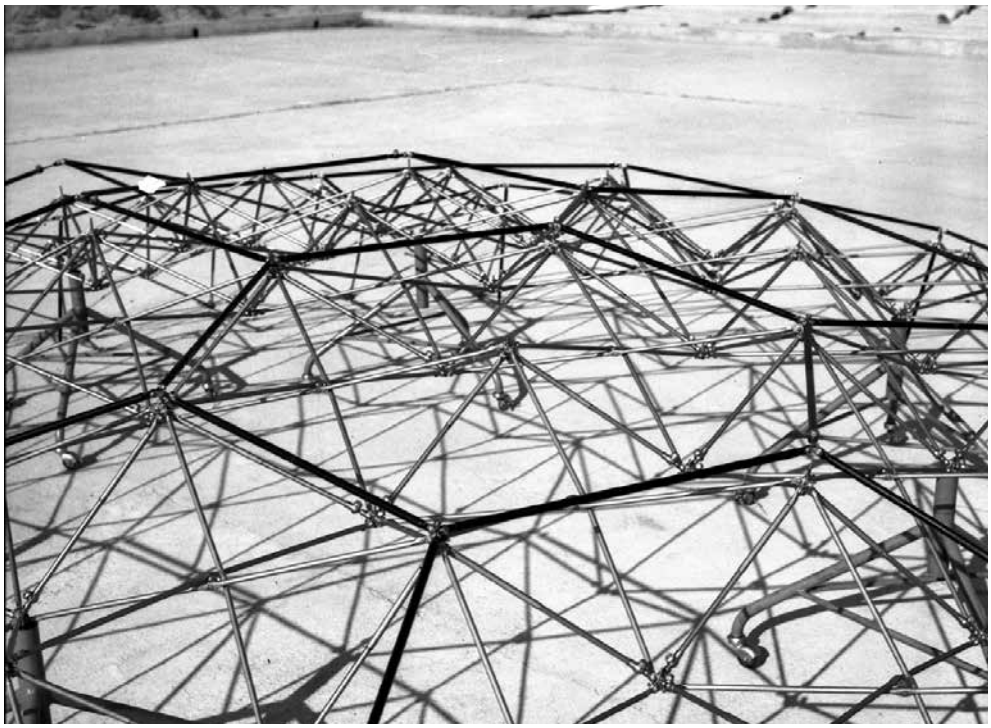

7 Pérez Piñero's ability to see in three-dimensional relationships of points in space allows him to conceive the project in a different and new way.

their resolution. The invention and brilliance in Pérez Piñero's work lies not so much in seeing what was hitherto hidden, seeing the principle or the concept – as is often understood by invention – but in the detailed resolution *[6]*.

Pérez Piñero's thought – both intuitive and deductive – reveals an exceptionally bright mind. This ability to see in three-dimensional relationships that other people have not seen before him allows him to conceive the project in a new way. Ten years after his first folding structure experience (the competition in 1961) Salvador Dalí commissioned him to design a screen to separate the two main spaces in Dali's Museum in Figueras.[36] Pérez Piñero's vision for the screen and the Cross he designed for Dalí are key to understanding this exceptional three-dimensional vision *[7]*. When most people see a folding mechanism expanding or contracting, they know it is made of rods and nodes and assume that each strut must be moving, as prescribed, from one position to another. This assumption stops them from seeing how the mechanism really works. Pérez Piñero, however, could see that he could restrict the movement so that the relationship of each set of four points remains unaltered and thus capable of bearing a rigid plane, as brittle as a pane of glass. The Dali Cross is probably the best example of a spatial translation in algebraic topology terms.[37] The algebraic topology spatial translation is where his mathematical and three-dimensional mind come together.

Pérez Piñero's process of realisation

Usually, Pérez Piñero made his projects in his workshop in Calasparra. One could say that invention happens in the mind of the human being who is able to foresee a hitherto untried possibility, which brings about a transformation and offers a final product that couldn't be predicted. Such a process happens first in the mind and is then replicated in the materialisation of the idea, which is nothing other than the process of the architectural project. Invention occurs, therefore, within this process and as a constituent part of the process. Invention is not only to see what hitherto has been hidden but to bring it to fruition, to materialise it. Therefore, in this case, one could take it further and say that invention takes place in the mind and in the hands. He made many of the castings needed for his structures himself and taught his assistants to do this too. While he thought like a mathematician he made like a craftsman.

There are precious few drawings, when the volume of built work is considered, especially in the ten-year span of his work. Only the *25 Years of Peace Exhibition* project involved the production of quite a number of drawings were produced, although not only by Pérez Piñero. The total number of drawings for other projects may be less than half a dozen. In the case of the *25 Years* Exhibition the structure was manufactured by a Construcciones Aeronáuticas SA (CASA) *[8]*. They demanded drawings in order to make the aluminium structure, roofing panels, and, where required, the very few cladding panels. But there is a further reason for this striking lack of drawings. Emilio Pérez Piñero's modus operandi was to work out the design in his head, not just the concept but right down to the detail. He was exceptionally good with his hands and his model making had been more than a hobby from his childhood days. He was very good at casting metals. Many of the workmen that helped him in the workshop were taught by him to make metal castings. If we add his out-of-the-ordinary three-dimensional vision to his drawing skills, his care in making models and the exceptional skill of his hands for casting metal, we can see there is no need for drawings.[38] While this explains the

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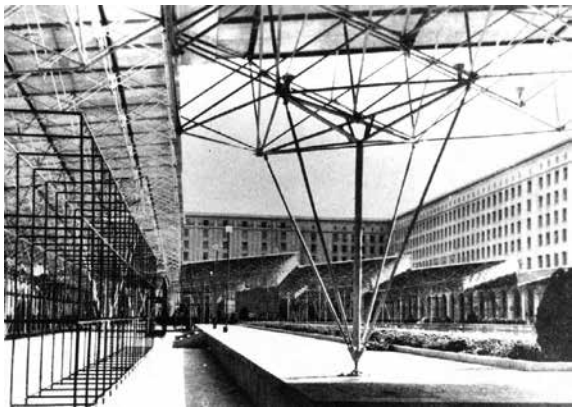
striking lack of drawn documentation, it goes some distance in explaining why there are so few models.

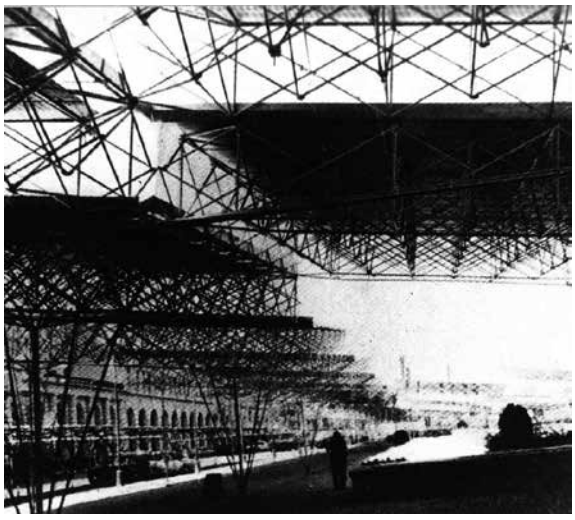
No one knows whether Pérez Piñero had drafted a plan of research, but it is unlikely he had even thought of the possibility. Probably he was relying on commissions to offer him the chance to push one or other aspect of his approach to design. We cannot therefore call his work prototyping in the sense that we mean it today. Because his research progressed as a result of commissions, he did not have the luxury of working through proto-types. But in the little time available to him for each project, he did establish a preference for a hands-on methodology.

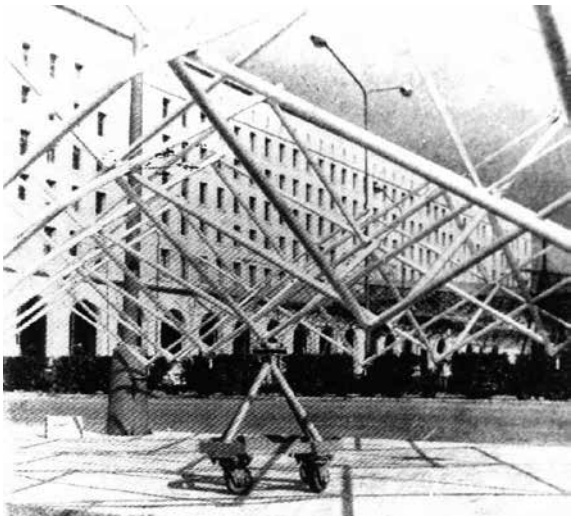
In some of his projects, there is evidence that he went directly into production without a testing model. But it was also his habit to reuse models from previous projects in order to test present ones. Frustrating for the curator and archivist but quite enlightening for the biographer.

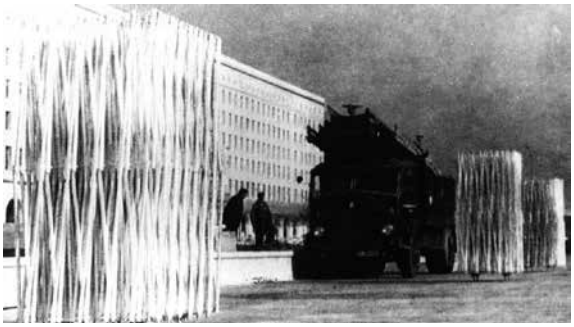
A career in invention

Emilio Pérez Piñero's work was interrupted by his tragic death on 8 July 1972. He was travelling back to Calasparra from Figueras, where he had been to oversee the progress of the works in the Dalí Museum. He was involved in a high-speed road crash and died instantly, in Torreblanca, Castellón.[39] He was, as he once said, a man in a hurry.[40] He always felt that he was very much on his own. As early as 1961, in the days immediately after the UIA Competition, his









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8a–f The Pavilion for the *25 Years of Peace* Exhibition is probably his most elegant work. Nothing there is superfluous, and everything seems to fall into place effortlessly.

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9 Pérez Piñero worked with a group of people in his hometown. He would have liked to have the support of the well-established laboratories and official institutes, such as the Torroja Institute but, he never received any help. He worked, as he said, 'in my loft, as it were.'

letters to his family show a great disappointment about those who promised to support him but in fact did nothing of the sort. Although he would have liked to have the support of the well-established laboratories and official institutes, such as the Torroja Institute, Pérez Piñero always worked with a team of people in his home town *[9]*. As he complained in an interview with Carmen Castro he never received any help, and worked, as he put it, 'in my loft, as it were.'[41] Pérez Piñero would have liked to develop each project faster but sadly his premature death left some projects that were clearly running behind schedule unfinished and undeveloped. This means a double challenge for those who wish to develop his legacy: to complete his work and to take it further from where he left it, especially the greater integration of the cladding or envelope with the reticulated structure.

A possible line of investigation waiting to be addressed today is the application of his folding structures to non-regular shapes. The folding structures Pérez Piñero worked on were either spherical or planar. This was because he was developing his inventions while responding to specific commissions. In those commissions (the Ambulant Theatre or the *25 Years of Peace* Exhibition) the regular geometrical shapes were the ones that best responded to the demands of the brief, but there is nothing about that would otherwise have prevented Pérez Piñero from devising alternative shapes. Anyone who thinks first of the shape and then tries to make it fold will very likely fail. Pérez Piñero's approach would have been to transform the regular geometrical mechanism into the desired form by adjusting the length of the rods and the points of incidence with the nodes, the nodes themselves. Pérez Piñero's extraordinary three-dimensional capacity for seeing these mechanisms in space was essential for this work. Finally, the great expectation for him and for all of us today, seems to be hinted at in the project of a large dome in seven sections (this he achieved in his lifetime) extending in some parts and retracting in others. This additional feature would have enabled Pérez Piñero to multiply the variations and alternative relationships between the folding structure and the ground and above all, between light and darkness inside the reticulated structure.

Pérez Piñero's attitude, his concerns, and the quest for the answers he sought belong to a historical moment in the second half of the twentieth century that seemed to be waiting for him. He was obsessed with his play of geometry and mathematics. The words of Richard Rorty, that 'the poetic, artistic, philosophical, scientific or political progress results from the accidental coincidence of a private obsession with a public need' seem to have been written with Pérez Piñero in mind.[42] His clear and orderly understanding of spatial three-dimensionality is no doubt the product of his exceptional mathematical mind, which so comprehends the geometry of the models in his mind that he is able to reach, to achieve, the right form, that comes closest to perfection as it reaches maximum simplicity.

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Notes

1. Reticulated structures are generally referred to as structure created with interconnected bars in the form of triangles to create a network. The joints of the bars are called nodes and they can be rigid or articulated.
2. The popular interpretation, that these buildings were the masterpiece of Franco's regime, is still today the story that most visitors are told. And yet it could not be more inaccurate. To start with the building in the background can be indeed considered a jewel in Spanish architecture. It ranks with best examples of the *Arquitectura Racional*, but they should not be attributed to Franco's regime or linked to its ideology. The idea behind the project and the design date from 1931, when Secundino Zuazo Ugalde was asked by Indalecio Prieto, then minister of Public Works, to provide the necessary plans for the new Ministries Buildings and a master plan for a rational growth for Madrid. Those who associate the severe and austere classicism of the *Arquitectura Racional* with Franco's regime or indeed with fascism, should bear in mind that this Secundino Zuazo was one of the founder members of the *Asociación de Amigos de la Union Soviética* (Association of Friends of The Soviet Union). The very same person too, that had to go to France in self-exile at the end of the Spanish Civil war and returned, three years later, to continue practicing and living in Madrid until 1971. Indalecio Prieto Tuero, born in Oviedo 14 April 1883, died in Mexico DF on 12 February 1962. He started as a journalist in Bilbao and then joined the Socialist Party. He served as a cabinet minister at the outset of the II Republic 14 April 1931, being Treasury Minister from the beginning of the Second Republic till December 1931 and then Minister of Public Works from 1931–3. He was a controversial character very ready to pull the trigger of his own pistol. The building of the Nuevos Ministerios was interrupted by the Spanish Civil War. Works were restarted after the war in 1942 and finally finished in 1960. The second phase was carried out to the original design by Zuazo under the supervision of a group of architects: Guillermo Diz, José Gómez Mesa, José Rodriguez Cano, and Miguel Angel Garcia Lomas. This last one was to become Director General for Housing and was the one who spoke to Salvador Dalí about Pérez Piñero.
3. The firm that built the aluminium structure, the roof and, were applicable, the cladding was Construcciones Aeronáuticas SA (CASA) located in Getafe, in the outskirts of Madrid, next to the military airport of that name. The structure consisted of a number of 'bundles' on castors that weight 500kgs and when folded measured 800 x 700mm and when extended measured 12 x 9 m. The floor area covered by this roof was 8,000 sq m.
4. Union Internationale des Architectes – International Union of Architects. Founded in 1948, the UIA is a federation of national professional organisations working to unify architects, influence public policies, and advance architecture in service to the needs of society.
5. NASA's interest in his work is difficult to assess. Felix Candela wanted to make Pérez Piñero known outside Spain, especially in North America. It is very likely that NASA's interest is due to Felix Candela's introduction to prominent members of NASA, known to him. Sadly, the unfortunate interference of third parties in his friend's business affairs kept him away from what would have been certainly a most exciting commission, especially through the mediation of such a loyal friend as Félix Candela. Indeed, great interest was shown by forward-looking institutions like NASA, etc., on his planar folding structures. It should not surprise anyone that the interest shown by NASA to Emilio Pérez Piñero's work was never expressed in detail. After all the approach was made by means of letters to Félix Candela, who acted as a go-between, and it is now well known that all correspondence from and to Félix Candela (in exile from Spain) at the time was intercepted by the Mexican Government Security Services. Therefore, one thing is certain: if any specific project was mentioned, by those in the know, it would have been, either by way of example, or mere speculation. Some have gone as far as to say that NASA wanted to engage Pérez Piñero's services for the design of dome structures to be deployed on the surface of the moon. This is not surprising since the contribution that Emilio Pérez Piñero made was not just the folding reticulated structure but its application of the to the deployable building. It seems, however, far more likely that NASA would be interested in Emilio Pérez Piñero's planar reticulated folding structures with the rigid glass panels stowed away within the folding structure, such as the Cross he did for Salvador Dalí whereas the military would be more interested on his easily transportable reticulated domes versions. The application of this invention to stow-away deployable solar panels would have been an equally direct and useful application. Of course, building on the moon appealed to the media much more that retractable panel. And that is how it has come down to those who have access only to the printed word.
6. Manuel Alejandro Rodenas-Lopez, Martino Pena Fernandez-Serrano, Pedro Miguel Jimenez-Vicari, Pedro Garcia Martinez, Adolfo Pérez Egea, 'Geometric Evaluation of Deployable Structures Using Parametric Modelling', *Nexus Network Journal*, 22 (2020), 247–70.
7. Federico Luis del Blanco García, 'Reconstructing Pérez Pérez Piñero's Anoeta Velodrome', *Nexus Network Journal* (2022).
8. Rodenas-Lopez and others, 'Geometric Evaluation of Deployable Structures Using Parametric Modelling'.
9. Jose Calvo Lopez and Juan Pedro Sanz Alarcon, 'Folding Architecture for an Astonishing Decade: Emilio Pérez Piñero and the Architecture of the Sixties', *EGA Revista de Expression Grafica Arquitectonica*, 17 (January 2011), 114–26.
10. The full extent of the maximum or minimum aperture may be of interest to those trying to measure empirically and as accurately as possible every aspect of the folding structure, but what is of great value to us is the fact that he conceived the unavoidable eccentricity as the means of controlling the geometry, which would achieve the static equilibrium. In other words, rather than a problem he sees in it a means of control and definition of his contribution: the way to convert a dynamic mechanism into a static structure. Likewise, the relation between the floor area covered, the length of the rod and the distance between the end of the rod and the node is an

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indicator of the efficiency of the system and the choice of the number of rods meeting at the nodes. The relevance in terms of what constitutes part of the invention is a geometrical one, that is, whether the angle of incidence to the ground will avoid lateral thrusts.

11. Calvo Lopez and Sanz Alarcon, 'Folding Architecture for an Astonishing Decade'.
12. del Blanco García, 'Reconstructing Pérez Pérez Piñero's Anoeta Velodrome'.
13. For an overall sense of the work carried out since Emilio Pérez Piñero's death, see: Rodenas-Lopez and others, 'Geometric Evaluation of Deployable Structures Using Parametric Modelling'.
14. Catherine Slessor, 'Architects Don't Invent They Transform', *Architectural Review*, London (2 March 2015).
15. The entrance exams for the army engineers were famous for being the most competitive and sought after in the country. Many of the higher ranks among the science faculties at university level, before and after the War, were graduates from the army engineering academies.
16. It is important to note that Emilio Pérez Piñero died a tragic death when he was still very young leaving a very impressive trail behind. The sources of information regarding his childhood are his surviving relations. There would be therefore an excusable tendency to make everything related to that young boy´s childhood into something extraordinary. (They are quick to tell you that he made his own toys and, depending on who tells the story, that the airplanes did fly.) María del Carmen Pérez Almagro, 'Estudio y normalización de la colección museológica y del archive de la Fundación Emilio Pérez Pérez Piñero' (PhD thesis, Universidad de Murcia, Departamento de Prehistoria, Arqueología, Historia Antigua, Historia Medieval y Ciencias y Técnicas Historiográficas, 2013), pp. 49–157.
17. We owe a great deal to María del Carmen Pérez Almagro for her excellent biographical study, undoubtedly the most complete and balanced of those consulted. Most of the information used here has been obtained thanks to her work: del Carmen Pérez Almagro, 'Estudio y normalización de la colección museológica y del archive de la Fundación Emilio Pérez Pérez Piñero'.
18. Juan Carlos Arnuncio Pastor, *El elogio de la arquitectura moderna,*opening lesson for the 2004–05 Academic Year at the University of Valladolid (2005), p. 25 <http://uvadoc.uva.es/handle/10324/4538> [accessed 28 July 2023].
19. The text of one such letters runs: 'Entonces Blanco Soler, Decano del Colegio de Madrid, se me acercó y me prometió tal cantidad de cosas que vergüenza me da apuntarlas aquí. Pero los españoles, por la noche, con la copa en la mano somos unos y por la mañana, con la bilis en el estómago somos otros. [Then Blanco Soler, Dean of the Madrid College of Architects, came close to me and promised such quantity of things that it is embarrassing to write them here. But we Spaniards, in the evening, glass in hand, are one way and in the morning with an empty stomach we are quite another.]' Pérez Almagro, Estudio y Normalizacion, p. 63. AFEPP, FEPP, nº de referencia: ES_FEPP_S1_02_00045 (AFEPP: Archivo Fundación Emilio Pérez Pérez Piñero and FEPP Fondo Emilio Pérez Pérez Piñero).
20. del Carmen Pérez Almagro, 'Estudio y normalización de la colección museológica y del archive de la Fundación Emilio Pérez Piñero'.
21. Ibid.
22. Zygmunt Stanislaw Makowski (1922–2005) was a British engineer of Polishorigin, who was professor in the University of Surrey.
23. Emilio Pérez Piñero did not speak a word of English, and Ricardo Urgoiti was fluent in English and became his interpreter during the whole trip.
24. Carlos De Miguel, the lecturer at ETSAM and editor of the Spanish magazine *Arquitectura* who accompanied them in this trip, heard all these presentations and was able to write the first article expressing his admiration for the project. *COAM – Revista Arquitectura* COAM, 30 (June 1961), pp. 27–35. Also, *Architects' Journal* <https://archive.org/details/sim_architects-journal_july-december-1961_134_index/page/n7/mode/2up> [accessed 28 July 2023].
25. One of the authors of this article, Professor Elisa Valero Ramos, was the architect responsible for the reconstruction of the restaurant designed by Felix Candela, Restaurante Manantiales in Xochimilco, Mexico (1996). During this time, she got to know Candela quite well and was able to appreciate his warm-hearted nature and the care and interest he took of all those round him.
26. The other author of this article, Javier Castanon, while still a fifth-year student at the Architectural Association (AA) was doing his technical study thesis on Emilio Pérez Piñero. He met Buckminster Fuller at the AA and spoke to him about Pérez Piñero for around twenty minutes with him. During that meeting Fuller said he considered Pérez Piñero a genius.
27. José Miguel de Prada Pool (1938–) pioneered pneumatic structures, working both as a theoretician and as the architect for projects such as Alcudia (1968), Ellipsoid (1969), Mobile Worm (1970), Instant City (1971), etc.
28. There were no contemporaries of his with as good a set of results as he obtained throughout his degree course. When one considers Pérez Piñero's success in the last two years of his university studies, it is not surprising that his contemporaries remained in his shadow.
29. Having said this, Pérez Almagro has interviewed a good number of his contemporaries at ETSAM and she reports that all of them consider him an exceptionally intelligent and hardworking man.
30. Examples of nomadic architecture such as Turkish yurt to the Mongolian ger or the Moroccan tent show supporting and supported elements. The time and effort needed for their deployment is ultimately what pushed their development towards an easier assembly and disassembly within the limits of their transportation. Labelle Prussin in her book *African Nomadic Architecture: Space, Place and Gender* (Smithsonian Books, July 1995) explains this development.
31. This generic term 'reticulated structure' refers to a structure created with interconnected bars in the form of triangles to create a network. The joints of the bars are called nodes, and they can be rigid or articulated. The type of node entails a difference in terms of load bearing, and each type is particularly suitable depending on the type of structure to be built. Articulated nodes only support axial stress – that is, the forces of traction and compression. Rigid nodes allow

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the bars to support the axial force, shear stress, and bending moment.

32. Probably the best example of all is Mero TSK. Mero was founded in 1928 by Dr Ing. Max Mengeringhausen, the pioneer of modular construction and the room framework derived from it.
33. In 1964, Spain celebrated twenty-five years of peace after the end of the Spanish Civil War. One of the ways in which Franco's government saw fit to celebrate these twenty-five years of peace was a great exhibition. The project was entrusted to Pérez Piñero although he had only just graduated as an architect.
34. Generalisations here impoverish the description of his work. Two sentences cannot possibly do justice to the arduous work of painstakingly checking each solution to obtain the maximum benefit from it. We mention cables and rods because these are the ones that are best illustrated.
35. The idea of carrying a deployable structure in the back of a carrier keeps on coming up and still no project has surpassed Pérez Piñero (not even Future Systems).
36. Salvador Dalí was thinking of asking Richard Buckminster Fuller if he would design a reticulated geodesic dome for his museum. Miguel Angel Garcia Lomas, then Director General for Architecture (1960–73) spoke to Dalí about Emilio. Dalí contacted Ricardo Bofill who put him in contact with Emilio Perez Pinero. Salbador Dalí claims that Fuller said, 'Perez Pinero does structures that I would not know how to do.'
37. Algebraic topology is a branch of mathematics that uses tools from abstract algebra to study topological spaces.
38. The architect usually needs drawings to develop the idea, to test it, and to convey it to the fabricator. The point we are making here is that Emilio Pérez Piñero developed the idea in his mind (hence no developing sketches); he had already tested the idea in his mind (no drawings here either); and he was the manufacturer who made his own castings.
39. Ibid.
40. He expresses this feeling several times when writing home. He is a man in a hurry that does not like to remain idle. Pérez Almagro, with the generous help of members of the Pérez Piñero family, has gathered the complete set of his writings and letters. In these writings, there are many instances where the clarity of his expressions reveals a mind that has both intuitively and logically deducted the full theory on which he based his design and the hands that have crafted the end result. The thought process is one where the form has been an integral part of the mechanisms from the very moment of inception.
41. See *Revista Arquitectura* COAM, 163 (July to August 1972), pp. 25–8.
42. Richard Rorty, *Contingency, Irony, and Solidarity* (Cambridge: Cambridge University Press, 1989), p. 37.

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Competing interests

The authors declare none.

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