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REVIEW

On the use of flexible formworks for concrete structures

Sobre o uso de fôrmas flexíveis para execução de estruturas de concreto

Murilo Schmidt Oliveira Soto[a]
Ruy Marcelo de Oliveira Pauletti[a]
Leila Cristina Meneghetti[a]

[a]Universidade de São Paulo – USP, Departamento de Engenharia de Estruturas e Geotécnica – PEF, São Paulo, SP, Brasil

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Abstract: This article presents a literature review on the use of flexible formworks for concrete structures, from their earliest conceptions in the late 19th century to recent applications. The challenges faced by builders, engineers, and architects in designing flexible moulds are discussed. A bibliometric analysis on the subject is also presented. Different methodologies for categorization are analyzed, and a consistent classification based on the application technique is proposed. Advantages and disadvantages of the formwork system are discussed and the article concludes with the perspective of future studies on the construction process through computational models.

Keywords: flexible formworks, concrete structures, shell structures.

Resumo: Neste artigo é apresentada uma revisão de literatura a respeito do emprego de fôrmas flexíveis para a execução de estruturas de concreto desde suas primeiras concepções, no final do século XIX, até aplicações recentes. Expõe-se as dificuldades enfrentadas pelos construtores, engenheiros e arquitetos na concepção de moldes flexíveis. Também é apresentada uma análise bibliométrica sobre o tema. Com base na análise das diferentes metodologias para a categorização das técnicas construtivas é proposta uma classificação condizente com as variadas aplicações. Discute-se ainda vantagens e desvantagens de diferentes tipos de aplicações, concluindo-se pela perspectiva de estudos futuros do processo construtivo por meio de modelos computacionais.

Palavras-chave: fôrmas flexíveis, estruturas de concreto, estrutura em casca.

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1 INTRODUCTION

The use of formworks in civil construction is linked to concrete applications, due to the need to shape the material during its non-hardened phase. Hurd [1] identified three main concerns of designers and builders regarding its use: *(1)* ensuring the quality of the elements, in prescribed geometries and positions, and in the concrete finishing; *(2)* ensuring the safety of the structure; and *(3)* seeking economy and building efficiency, at a lower cost and in less time.

Melaragno [2] reports that the first material used for formwork was wood, using solid logs or plywood sheets, resulting in a good solution for both reticulated and continuous geometries, either flat or doubly curved. However, the execution of complex geometries using flat wooden formworks might become too costly and render construction unfeasible.

Hurd [1] points out that the cost of formworks greatly impacts the total cost of reinforced concrete structures, ranging from 35% to 60%. Maranhão [3] mentions a range of 40% to 60% for the formworks in the total cost of the concrete structures, or from 8% to 12% of the total cost of a building. Motivated by this relevant cost component, as well other characteristics such as improving the concrete finish on the surface near the form, the speed of execution and the

Corresponding author: Murilo Schmidt Oliveira Soto. E-mail: murilo.soto@usp.br
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feasibility of complex geometries, several inventors and researchers strive to develop alternative to the use of traditional formworks, in particular flexible moulds.

The distinction between conventional rigid and flexible formworks is related to their behavior when subjected to the loads imposed during the concrete casting. Schodek and Bechthold [4] define rigid structures as those that do not present relevant changes in their geometry due to the variation of the applied loads. Flexible structures, on the other hand, might present drastic geometry changes according to the applied load, assuming a certain shape for a specific load condition, a concept that can also be extended to temporary structures such as the moulds used for the conformation of fresh concrete (Figure 1).

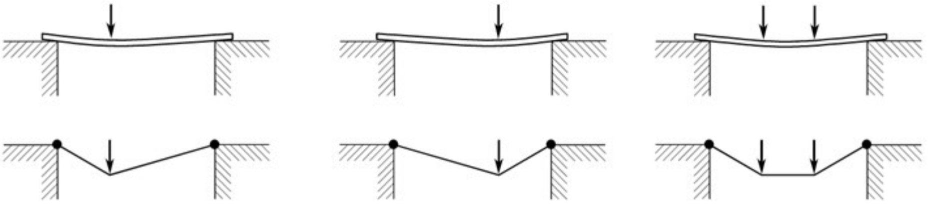


Figure 1. The distinction between rigid and flexible structures. Adapted from [4].

Therefore, based on this definition, flexible formworks can be described as temporary support structures that are susceptible to applied loads, which may result in substantial variations in their geometry.

In this paper, a review is presented on the evolution of this formwork system for shaping concrete structures, highlighting the challenges and major advances proposed along the years, as well as indicating potential technological advancements. To avoid excessive repetition, the paper also uses the alternate expression "flexible mould" and "flexible formwork" basically with the same meaning.

2 HISTORICAL DEVELOPMENTS

The first known use of a fabric formwork for concrete shaping is attributed to Louis Lilienthal [5], who in 1899 designed a fire-resistant slab, as shown in Figure 2. The invention consisted of applying concrete onto a sufficiently impermeable fabric, covered with reinforcement bars.

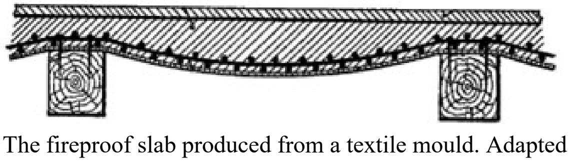


Figure 2. The fireproof slab produced from a textile mould. Adapted from [5].

Lilienthal [5] attached the fabric formwork to wood beams, without fully stretching the fabric, which therefore assumed a funicular geometry under the weight of the fresh concrete. According to the author, this geometric arrangement allowed the reinforcement to develop tensile stresses, resulting in a considerable increase in the structural resistance. With this technique, Lilienthal built more than 30 low-price houses in Berlin [6].

Other inventors patented variations of Lilienthal's original technique, bringing different types of improvements, and extending the fields of application. In 1917, Fletcher [7] generalized the technique to other structural elements (Figure 3), including beams with variable cross-sections, and highlighting the possibility of obtaining uniform stress states (close to the "theoretical form") and the material and time savings allowed by the technique.

Three decades after Lilienthal's invention, in 1928, Govan and Ashenhurst [8] patented a similar construction process using a gypsum-based material, aimed at improving the thermal insulation of buildings (Figure 3). The authors also pointed out the benefits resulting from the use of textile formwork, such as material and labor savings.

Later, in 1937, Farrar et al. [9] suggested improvements regarding the construction process as the application of concrete in two layers, with the positioning of the reinforcements between the two concrete pourings (Figure 3). They also mention the possibility of using various materials for formwork, including paper and "leaf or grass mats" depending on local availability, and the ease of execution, making the method appropriate for locations where specialized labor was scarce.

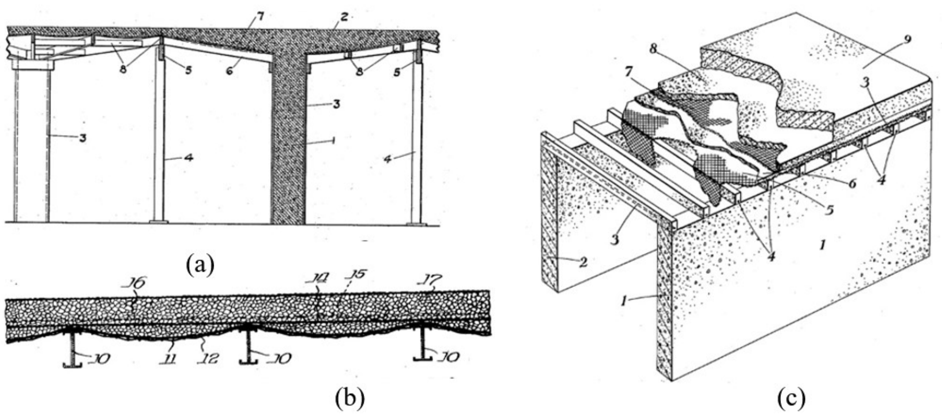


Figure 3. Improvements made by (a) Fletcher [7]; (b) Govan and Ashenhurst [8] and (c) Farrar et al. [9].

According to West [6], James Waller was responsible for some of the most relevant improvements of Lilienthal's technique. Through experimental observations, Waller [10] developed in 1934 a system for casting concrete onto a natural fiber fabrics, stretched over a wooden structure (Figure 4), later patented as the "Nofrango" system [11].

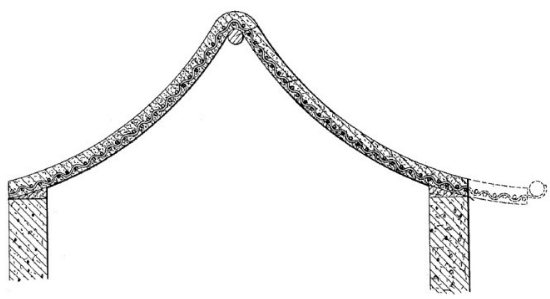


Figure 4. A coverage produced with a fabric mould. Adapted from [10].

Differently from the previous patents, Waller [10] mentioned that the fabric can be adopted as a lost formwork and considered as a reinforcement for the produced structure, without the need of further reinforcement such as steel bars or wire meshes. Regarding the tensioning of the formwork, Waller [10] also mentions the importance of wetting the fabric after its fixation, as the shrinkage resulting from the moisture provides additional traction of the fabric and facilitates the penetration of the mortar into the fabric pores. The savings allowed by the proposed technique and the solidity and lightness of the final structure presents are also highlighted by the author.

In addition to the Nofrango system, Waller patented several other applications that can be categorized according to the tensioning of the formwork and the application of the mortar. According to Veenendaal et al. [11], these categories are: *(1)* fabric stretched in one direction and stiffened (slabs and roofs); *(2) fabric* stretched in two directions and stiffened (walls); *(3)* fabric filled and stretched by hydraulic pressure (columns); and *(4)* fabric extended on the ground (foundations and slabs on the ground).

Waller's work would reach its peak with the development of the first application of a textile formwork for the construction of shells [6]: the "Ctesiphon" system, whose name was inspired by the Taq-i-Kisra arch of the ancient imperial city of Ctesiphon, on the outskirts of Baghdad, Iraq (Figure 5). Waller observed that the slackness of the formwork between its support points caused a ripple in the fabric, which when applied over arches spaced parallel and within a suitable "arrow", promoted additional stiffening to the shell produced [6]. Thus, designing the support arches by analogy to the inverted catenary cable, the need for reinforcements for the shell was minimized [11], even being discarded in the production of two prototypes of 12 and 32 meters of span [6], built in 1943, whose construction process is illustrated in Figure 6.

Figure 5. Taq-i-Kisra arch of the ancient imperial city of Ctesiphon, Iraq [12].

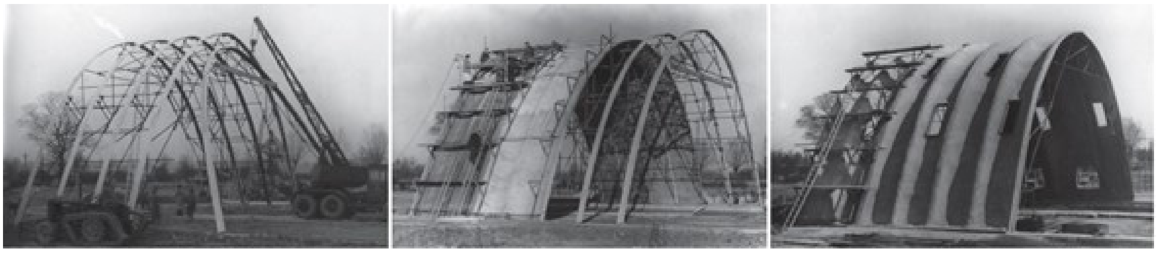


Figure 6. Construction process of the “Ctesiphon” system. Adapted from [6].

Due to its fast production, without the need for specialized labor or reinforcements, the Ctesiphon system proved to be competitive during the Second World War, where there was a high demand for structures with large spans. At least 50 concrete shells were built by that time, spanning from 6 to 12 meters [6]. In 1954, Waller made modifications to his Ctesiphon system to produce circular shells and domes, employed in various constructions, including homes, silos, and industries, in different countries around the world. Other early applications of textile formworks, addressed by Waller but divergent from the work developed by Lilienthal, regard the use of fabrics for submarine and geotechnical structures [11].

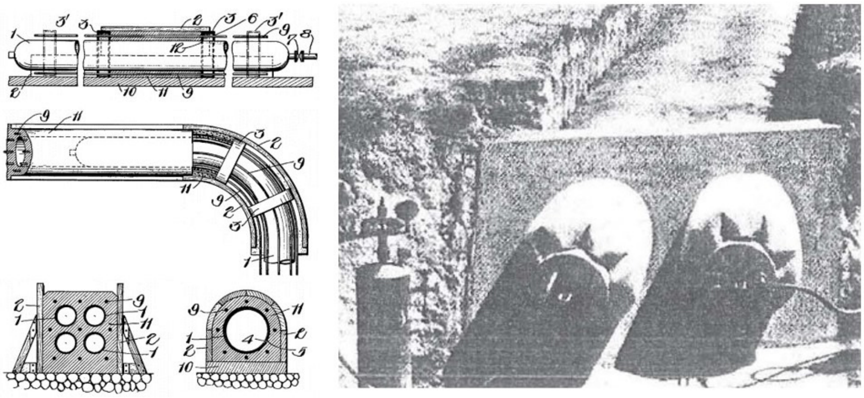
In 1911, Condie [13] developed a slope protection structure produced by filling a fabric mattress with concrete. In 1922, Store [14] conceived a similar method for concrete casting foundations, breakwaters, and jetties, but the concrete casting of the fabric envelopes was carried out underwater. Textile formworks were also extensively explored by renowned architects in the second half of the 20th century, such as Heinz Isler, Antoni Gaudí, and Felix Candela [15].

In addition to the use of natural fiber fabrics, a series of other applications using synthetic fibers emerged in the 20th century, more geared towards the use of pneumatic envelopes. Although the commercial availability of synthetic fibers only became consolidated from the 1950s onwards [16], applications using plastic membranes had already been conceived since the beginning of the 20th century, such as Boyle’s apparatus to cast hollow concrete elements in 1907 [17].

In 1927, architect Normand W. Mohr referred to some recent pneumatic systems (at that time) for the construction of an underground passage in San Francisco Bay. Mohr suggested the execution of submarine tubes with inflatable formworks and the transportation of the tubes to the site by flotation, potentially generating a saving of up to two-thirds of the cost of a suspension bridge [18].

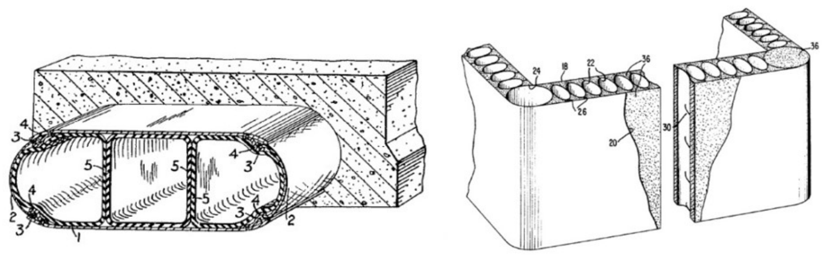
One year before, Nose [19] had already patented a similar system for producing concrete pipelines for water and sewer services as well as drainage galleries of any length and without seams, including curved sections, as illustrated in Figure 7a. Improvements for the protection of the inflatable membrane and several cross-section geometries lead to the publication of another patent in 1931. Figure 7b shows an application of Nose´s method, where in which a pneumatic formwork was used to construct a water pipeline in Italy in 1938, as mentioned by Sobek [20].

Similar concepts were proposed by Mathews and Ambrose [21] in 1945 for manufacturing hollow concrete bricks with a non-circular core, while Mora [22], in 1968, designed a system for producing lightweight hollow concrete panels, as illustrated in Figure 8. In both cases, the hollow regions of the pieces are delimited by inflated tubes, resulting in less material consumption and lighter pieces.



(a) (b)

Figure 7. (a) Apparatus for concrete casting pipelines using inflatable tubes –adapted from [19] and (b) construction of a pipeline in Italy in 1938 –adapted from [20].



(a) (b)

Figure 8. Use of inflated tubes to produce hollow bricks – (a) adapted from [21]; and use of inflated tubes to produce lightweight hollow concrete panels – (b) adapted from [22].

In 1955, Leonhardt [23] had already patented a system for producing prestressed sheaths using inflatable tubes and metal rings, and seeking to reduce the friction between the membrane and sliding reinforcement cables.

As per the use of pneumatic membranes for shell construction, the first inventions appeared around the 1940s. In 1942, Wallace Neff [24] developed a pneumatic system for building housing and barracks, with minimal costs and fast execution. The system, illustrated in Figure 9, consisted of pressurizing a membrane with the desired shape, anchored by cables fixed at the lower edges, after the installation of the supports of the final structure [24]. The reinforcements were placed over the inflated membrane and the openings for doors and windows were provided by stiff frames. Then, the structure was covered with concrete until the desired thickness is achieved. The deflation of the membrane was done only after the concrete cured, when the membrane easily detached from the hardened concrete shell. To restrain the horizontal thrust of the borders of the shell, additional reinforcement rings were placed along the perimeter of the structure.

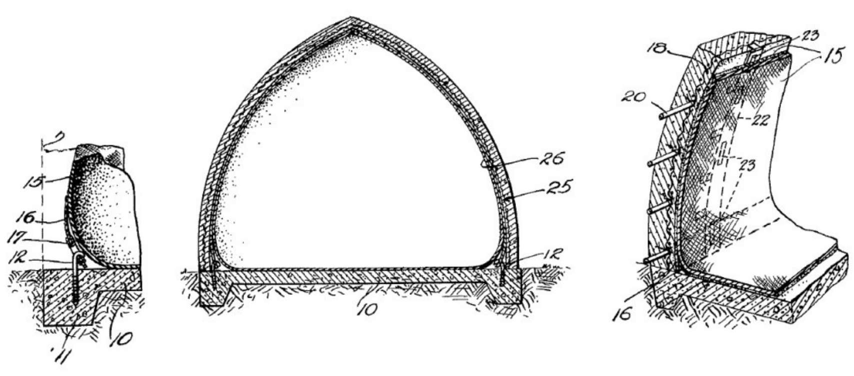
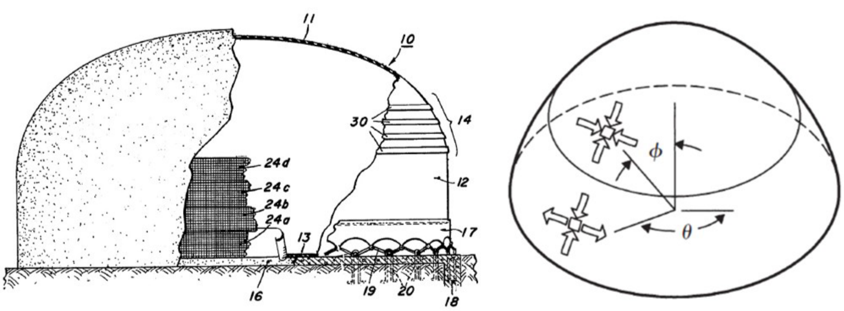


Figure 9. The Neff system for executing shells with inflated membranes. Adapted from [24].

In 1959, Neff [25] deposited a new patent to tackle the problems of cracking displayed by domed shells at the side wall region, below the horizontal plane defined in the Figure 10b. In that region tension hoop stresses arise in conventional shells. Therefore, Neff devised special hoop reinforcement rings at this region, identified as number 14 in Figure 10a. Similar improvements were also proposed afterward by Turner [26], Heifetz [27], Provoust [28] and South and South [29].

Figure 11 shows the idea of Turner [26], similar to South and South [29], which consisted in the application of polyurethane foam to the inside of the inflated membrane, thus producing a stiffening of the pneumatic formwork for subsequent concrete application. In addition, the plastic layer formed assists in the waterproofing of the structure.



(a) (b)

Figure 10. (a) Improvements to Neff system - Adapted from [25] and (b) identification of the horizontal rupture plane, which in the case of spherical shell corresponds to $\phi = 51,5^0$ - Adapted from [4].

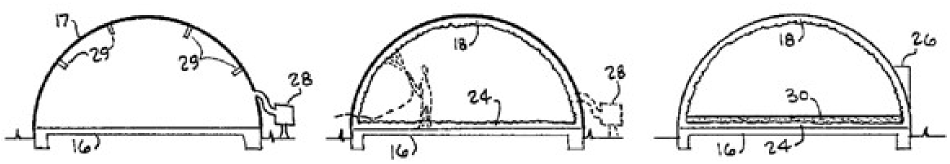


Figure 11. Internal stiffening of the pneumatic casing before the external application of concrete. Adapted from [26].

In 1972, Heifetz [27] proposed a system similar to Neff's, but with higher pressures, ranging from 4 to 10 kN/m^2 [30], while Neff's membranes were pressurized in the range of 0.5 to 2 kN/m^2. Heifetz also invented a system for anchoring the membrane using a rigid ring at the base of the structure (Figure 12), capable of absorbing the stresses imposed by the membrane inflation, thus relieving the loads on the foundation. With the so called “Domecrete Building System” or “Heifetz System”, which construction stages are indicated in Figure 13, several structures were built in countries such as Israel, South Africa, Bolivia, Italy and Iran.

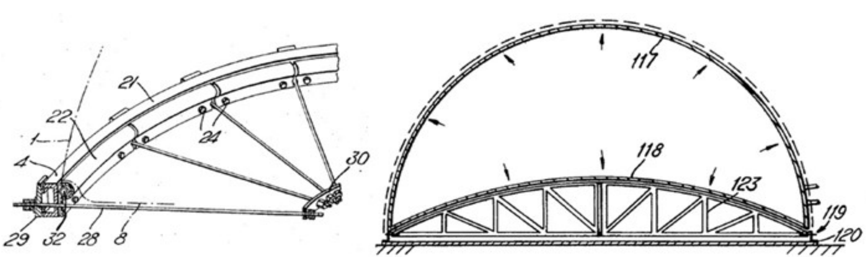


Figure 12. Stiffening of the foundation with the use of a rigid ring. Adapted from [27].

Figure 13. Stages of construction of the Domecrete Building System. Adapted from [31].

Provoust [28] also identified, in 1978, the loads required to anchor the membrane as a major disadvantage of pneumatic formwork system. Thus, he designed a secondary, toroidal pneumatic system, at the base of the main formwork, with separate air chambers, eliminating the up-lift loads (Figure 14).

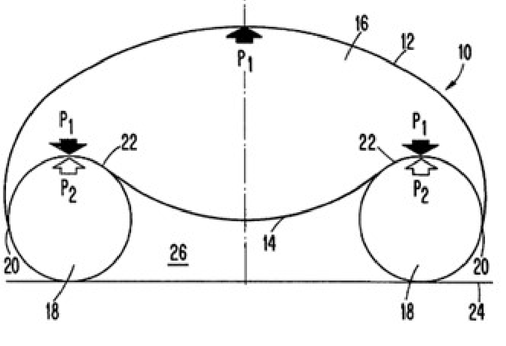


Figure 14. Design of a secondary pneumatic enclosure at the base of the membrane. Adapted from [28].

The construction methods with pneumatic envelopes presented considered the inflation of the membrane formwork before the concrete casting. A departure from this assumption was taken by the Italian architect Dante Bini in the late 1960s, which consider the deposition of concrete before the inflation of the formwork. Besides this reverting the steps of concrete deposition and formwork inflation, Bini [32] also proposed the use of an extendable reinforcement mesh, capable of fitting the formwork three-dimensional geometry, as illustrated in Figure 15. He also mentioned that natural or synthetic fibers could be used instead of steel reinforcement.

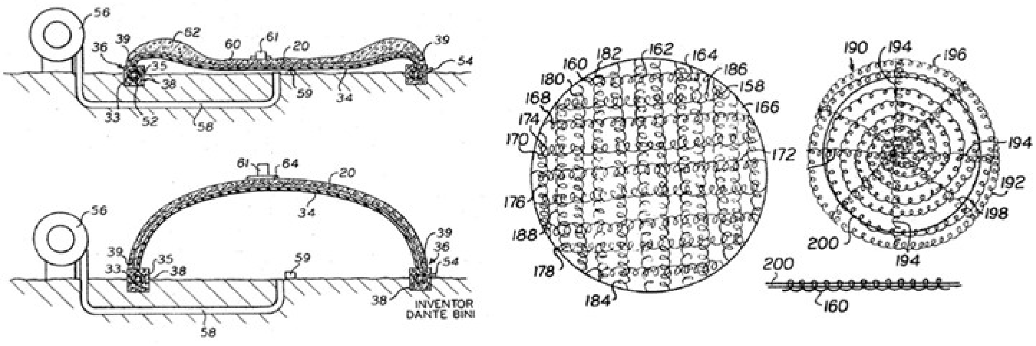


Figure 15. Construction method and disposition of reinforcement in Bini's shells. Adapted from [32].

Pugnale and Bologna [33] report that in Bini's first prototype, made in 1964, the fluidity of the concrete was restricted by a mesh, resulting in a granular and uncompacted finishing, which was corrected by the manual smoothing of the surface. In 1967, after conducting new experiments and creating his company “Binishells Spa,” Bini performed a demonstration on the campus of the Columbia University in the United States, installing a second membrane over the concrete, before inflation, thus improving the finishing of the final shell. In addition, it was possible to mechanically vibrate the concrete with the aid of cables, laid over the upper membrane. Through this new process, Bini [32] patented, in 1969, a series of new applications, presenting in detail the connection between the membrane and the foundation and different means of inflating the pneumatic formwork. In his patent, Bini reported that after World War II, the cost of labor for buildings had become a major concern, asserting that his invention was capable of significantly reducing the costs of shell constructions, compared to existing methods. By 1971, Bini´s method had gained international recognition, with pneumatic shells being executed in more than 20 countries [33]. In 1973, by invitation of the Australian government, Bini produced a series of more than 20 public education buildings, using his construction process.

Generally speaking, all the above inventions, related to the use of textile or pneumatic formworks for concrete casting, claimed reduction of the production costs, with compared to the conventional wooden formworks, both in terms of material and labor. In 1969, Parker [34] estimated a 20% cost reduction in achieving “parabolic” geometries compared to the cost of conventional wood formwork or precast elements.

The success of the methods developed by the South and Bini raise market awareness of pneumatic formworks as a viable construction option. Furthermore, around the 1970s, the texture of the shell surface resulting from the textile formwork also started to catch the attention of designers and builders. The aesthetics obtained with the use of textile formworks was first explored by the Spanish architect Miguel Fisac, interested in embedding his work a unique expression [35]. With this technique, Fisac designed buildings with architecturally innovative facades, such as the MUPAG clinic in Madrid (1969-1973), the Tres Islas hotel in Fuerteventura (1970-1973), the Viviendas Del Parterre building in Daimiel (1978-1982), among others [6], [35], as the examples shown in Figure 16.

Figure 16. The MUPAG Clinic [6] and the Viviendas Del Parterre building [35].

The Japanese architect Kenzo Unno, in the 1990s, also developed a system of modular panels using fabrics as formwork [36]. It was a low-cost method for producing walls, consisting of a fabric fixed to a mesh of points, like the pillow buttons [6].

At the same period, Mark West, from the University of Manitoba, also began to experiment with textile formwork to produce elements such as columns and beams, eventually founding the first research center dedicated to the subject, the "Centre for Architectural Structures and Technology" - CAST [37].

Nowadays, the use of pneumatic formworks can be considered a mature technology and continues to attract researchers and companies, providing a plentiful of applications. Moreover, the non-pneumatic, flexible formworks, such as prestressed cable-net and membrane regained attention. An outstanding example is provided by the roof of the HiLo module at the NEST laboratory in Switzerland [38], a sandwich-type shell consisting of a rigid polyurethane core executed through a mechanically prestressed flexible formwork, formed by a suspended cable network. Also relevant is the curvy concrete shell molded on a prefabricated fabric and cable network conceived in homage to the architect Félix Candela, the KnitCandela [39], exhibited at the University Museum of Contemporary Art (MUAC) in Mexico City in 2018. Commercial applications such as the Fastfoot® foundation system from the Canadian company Fab-Forms [40] and Concrete Canvas® [41] aimed at protecting slopes and quickly deployable inflatable shelters, are finding an increased use. Another novel line of research considers the use of bending-active systems, for instance [42], [43].

The success of these recent academic and commercial cases encourages further studies aiming to broaden the application of flexible formworks. New experimental resources include digital image correlation (DIC), ultrasound and tomography. New materials include UHPC, foam concrete and geopolymers. Moreover, with the availability of advanced structural analysis software, capable of performing shape finding and optimizing routines, solve geometrically and materially nonlinear analysis, considering orthotropic materials and layered shell finite elements, it is nowadays possible to perform accurate predictions of the final geometry and the structural performance of concrete structures produced with flexible formworks. A non-exhaustive list of recent research includes references [44]–[45].

The authors have developed a series of small-scale models of flexible formworks based on pneumatic and tensioned membrane structures [46], as well geometrically nonlinear finite element models, capable of representing the concrete casting in sequential layers. Description of these models fall outside the scope of the current review and will be the subject of forthcoming papers.

3 BIBLIOMETRIC ANALYSES

A bibliometric analysis was conducted using data from Web of Science and Scopus databases, employing the *bibliometrix* package [47]. The survey was based on the terms "flexible formwork", "textile formwork", "fabric formwork" and "pneumatic formwork", resulting in 182 documents between the years 1983 and 2023, including articles, books, book chapters, and conference papers.

Figure 17 shows the annual global scientific production data, as well as the annual production of authors with the highest contributions over time in terms of the number of documents, in descending order. The documents with the highest number of citations for each keyword are indicated in Figure 18.

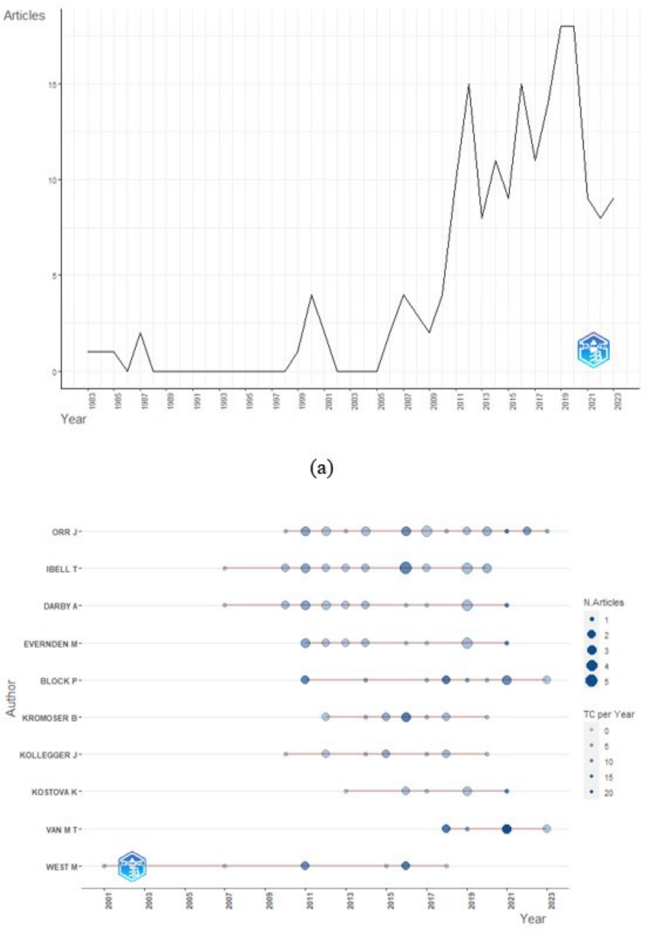


Figure 17. Annual scientific production and authors' production over time [47].

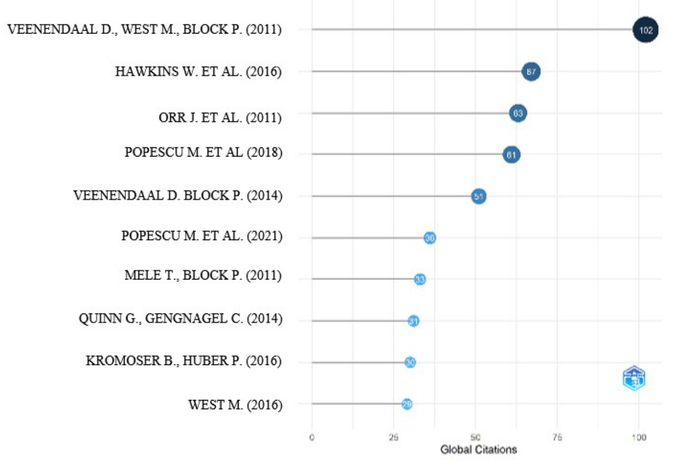


Figure 18. Most cited documents in the research field. Adapted from [47].

In Figure 19, the scientific production of each country is indicated, along with the countries of origin with the highest citation numbers. The most frequent terms in the database consulted over the years are reproduced in Figure 20.

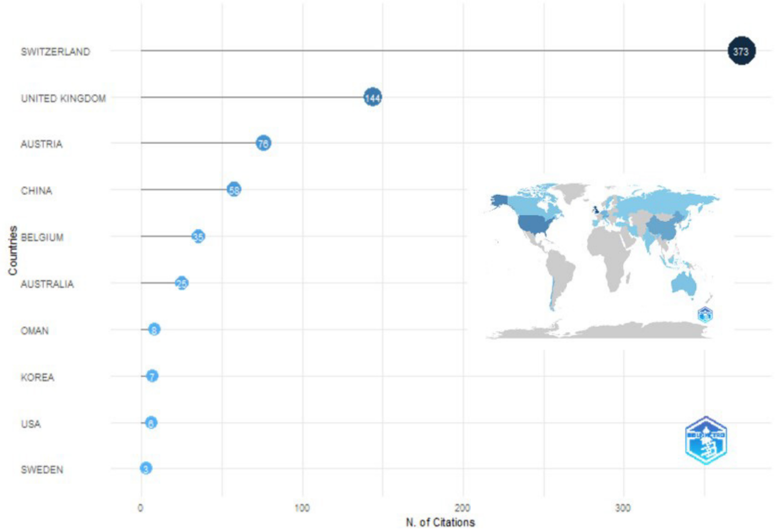


Figure 19. Scientific production by country and most cited countries [47].

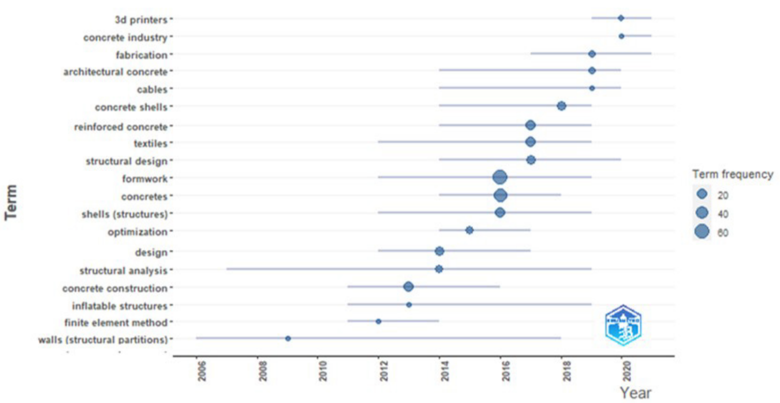


Figure 20. Trending topics over recent years [47].

The analysis reveals a growing interest in the topic of flexible formworks in the last decade, with a significant production of content particularly in Switzerland, United Kingdom, Austria and China. It is interesting to highlight that the "trendiest topics", *i.e.*, the most frequent cited terms are "3D printers" and "concrete industry". It is noted also the prevalence of the term "structural analysis" over the years, and indeed structural behavior is a matter of a permanent concern in the use of flexible formwork, both for safety and performance reasons and, in particular, for predicting the final geometries achieved with the use of flexible formwork.

4 CATEGORIZATIONS

Authors have proposed different categorization of flexible formworks into families, based on the nature of the forces acting on the formwork or on the geometry that can be achieved through its use. Isler [48] studied five different techniques in his shell experiments: pneumatic method; suspended membrane method; resetting elastic membranes in different frames, with fixation at their edges; flow method; and other combined or uncombined techniques. Abdelgader et al. [15] proposed a classification into four main groups based on the behavior of the mould, the geometry and usage of the structure, identified in Figure 21.

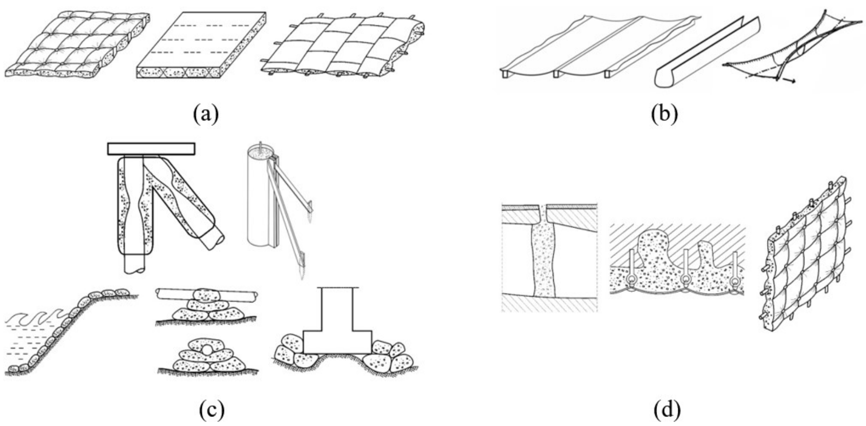


Figure 21. Types of flexible moulds according to Abdelgader et al. [15]: (a) cushion moulds; (b) open moulds; (c) bag-type moulds; (d) covering moulds. Adapted from Abdelgader et al. [15].

According to Veenendaal et al. [11] and Hawkins et al. [49], flexible formworks can be divided into two categories: filling and surface moulds. Different building elements can be obtained in each defined category, as shown in Figure 22.

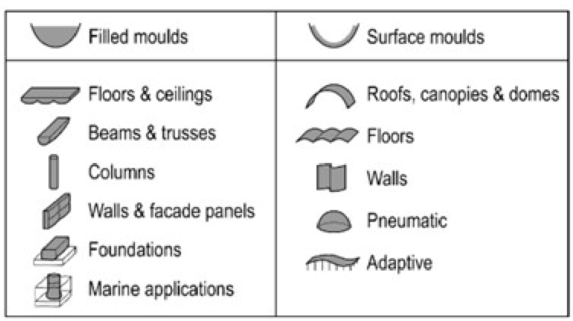


Figure 22. Categorization according to Veenendaal et al. [11]. Adapted from Hawkins et al. [49].

While the structural elements obtained through filling moulds present similar casting processes, those obtained through surface moulds may require different production. Surface moulds are those in which the applied concrete or mortar is not laterally confined, and its flow is controlled through the fluidity of the material itself.

Based on the applications studied and developed throughout the 20th and 21st centuries, and also the studies conducted with small scale experiments [46], in this paper we proposed that flexible formwork can be divided into two main branches according to the construction method employed: 1) filled moulds and 2) surface moulds as sketched in Figure 23.

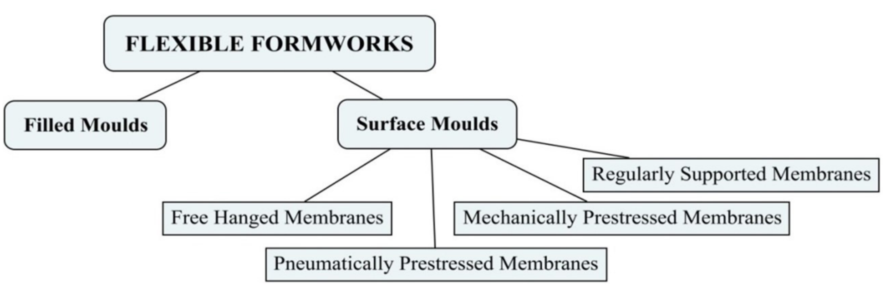


Figure 23. Proposal for flexible formworks categorization into families [46].

The "surface moulds" branch splits into four sub-categories. The first of them are the shells generated by free hanging membranes, in which the force of gravity from the structure itself gives rise to a purely tensile funicular geometry. Funicular concrete shell can be designed by inverting the position upside-down, such that the shell becomes fully compressed. In this category are the shells studied by Isler [48], as illustrated in Figure 24.

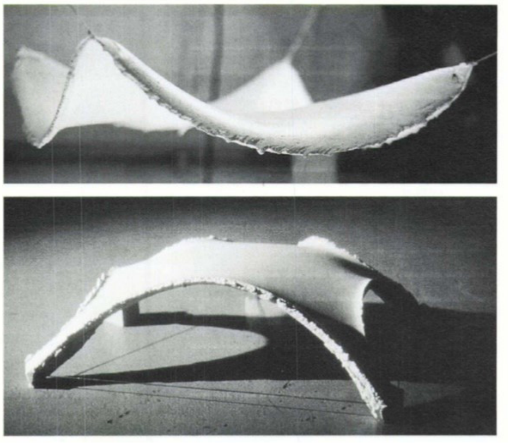


Figure 24. Isler shells generated by suspended fabrics. Adapted from [48].

The second method involves the family of shells produced using taut membranes or cable-net as formwork, usually with anticlastic geometries. This is the case with the cover of the HiLo module of the NEST laboratory [38], which formwork combines cable-net with fabric panels.

A third method involves the use of pneumatic membranes as formworks for the casting or erection of concrete. The geometries produced are usually synclastic. For this family of geometries, additional equipment is required for inflation and support of the mould. As previously mentioned, this type of formwork was widely used by Bini in the 1970s [32], [33], with some latter construction improvements, such as the process presented by Kromoser and Huber [30], called "Pneumatic Forming of Hardened Concrete (PFHC)," illustrated in Figure 25.

Figure 25. "Pneumatic Forming of Hardened Concrete (PFHC)" construction process. Adapted from [30].

Finally, in the fourth sub-category, the geometry of the structure can be obtained from flexible moulds supported along the entire surface by regularly distributed supports, or from the ground itself, such as the construction process associated with the Concrete Canvas® product used for slope protection [41]. In this case, the mould is not subjected to pre-tensioning, nor inverted as in the case of free hanging moulds.

5 CONCLUSIVE REMARKS

A literature review reveals an increasing interest on the use of flexible formworks for concrete structures in the last decade. Recent research focusses on problems related to the deformability of the moulds, the quality of surface finishing and the high prestressing loads required to stiffen the mould, as well as the importance of the non-linear analysis for form finding and structural assessment.

The historical review identified cost reductions, more efficient geometries, fast production, reduced mobilization on the construction site, and the attainment of aesthetically intriguing finishing as advantages of flexible formworks when compared to traditional formwork systems.

The first applications were based on intuitive design, using suspended fabrics for casting flat slabs and using flexible filling moulds for casting maritime and slope protection structures, without pre-tensioning, and mostly concerned about cost reductions.

Savings stem not only from the reduction of material required to produce formworks, but also from more efficient geometries when compared [24], [25], [27], [31], [32]. In particular, Parker [34] pointed out that flexible formwork could save up to 20% of the structural concrete required for producing parabolic geometries. Further savings are related to reduction in labor time, both in production of the formwork and in the installation on site.

On the other hand, in many cases, flexible moulds are one-way structures, allowing just a single casting, as in the case of filling moulds used in slope protection [13] and foundations [40]. However, sometimes the mould can also be incorporated into the final structure, acting as reinforcement for the concrete as suggested by Waller [10].

Early uses flexible formworks involved natural fabrics, usually made of jute or sisal, which have been gradually replaced by synthetic fabrics. By the mid-1950s, impermeable synthetic fabrics were developed with time becoming the standard material for textile moulds and membrane structures in general.

Since in most cases durability of flexible formwork is not a major concern, the use of natural fiber fabrics is regaining momentum, due to their low cost and especially lower environmental impact with mechanical properties comparable to synthetic fibers. Improvement of natural fiber fabrics is an open research line. Also, the use of permeable fabrics has been explored as a way to allows excess water to be exuded during the concrete curing potentially improving the tensile strength on the surface of concrete due to the reduction in concrete carbonation and the chlorides and oxygen influx [37].

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Author contributions: MSOS: conceptualization, methodology, formal analysis, investigation, writing – original draft; RMOP and LCM: supervision, formal analysis, writing – review and editing.

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