Building with Air: The Pneumatically Powered Construction Systems of Dante Bini

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Introduction

In July 1964, Italian Architect Dante Bini (1932–) successfully constructed (in three hours) a 12 metre diameter, 6 metre high hemispherical reinforced concrete shell structure (Fig. 01) on the outskirts of Bologna. Bini had tested (for the first time) his unique system of inflated fabric formwork to lift and shape the concrete. Bini had been inspired by the concrete shell structures of Pier Luigi Nervi, but was simultaneously frustrated by the expense, time and material wastage associated with the timber formwork necessary to construct such forms. By using a low-pressure inflatable membrane (which Bini entitled pneumoform) to both lift and form the concrete, Bini managed to entirely obviate the need for timber formwork. The 1964 prototype subsequently became the *Binishell*, a patented technology licensed across the world to construct housing, sports facilities and industrial buildings such as agricultural stores.

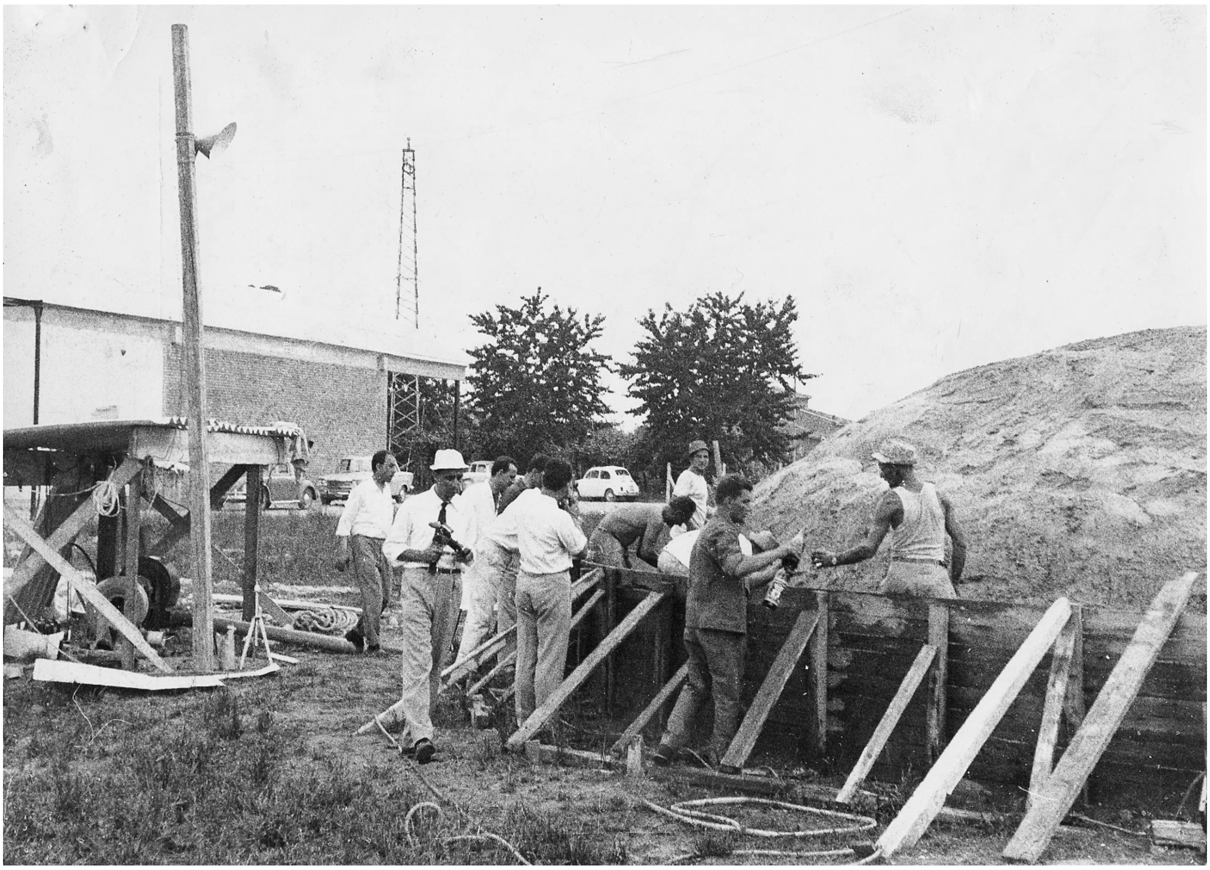

Figure 1. Crespellano, Italy. Architect, Dante Bini. The first Binishell under construction, 1964. Private archives of Dante Bini.

The paper will explore the development of the *Binishell* construction process as well as the subsequent family of pneumatic construction systems developed by Bini including the *Binix*, *Binistar* and *Minishell* systems. I will also examine the relative industrial success of these systems and the perceived difficulty in the commercial acceptance of such novel technological inventions and innovations. The paper has been written using primary sources including site visits, interviews and conversations with Dante Bini, and original documents including previously unpublished photographs, and commercial ephemera such as brochures.

The origination of the Binishell

Dante Bini recounts a story of playing a game of tennis in an air-supported fabric dome in January 1963 in Bologna. Having finished their game, Bini and his tennis partner were unable to leave the dome because during play almost half a metre of snow had fallen, temporarily blocking the entrance. What struck Bini was the heavy mass of snow that was being supported by the dome. "I did a quick calculation of the approximate weight of the snow amassed on the surface of the structure which, inflated at low pressure, was supported by just a few hundredths of an atmosphere – in technical terms, only 3.45 kPa (0.5 psi) literally supporting tons of weight!"[i] Only a year and a half later Bini was able to realise his first version of what became known as the Binishell. Through a series of iterations between 1964–68, Bini utilised an inflated pattern-cut membrane to lift and form concrete shell structures, which was common to all of the prototypes and early commissions. The developments and innovations through the iterative construction process explored differing cross-sectional geometries, alternative fabric types, and perhaps most importantly alternative methods of steel reinforcement and of resisting the pressure during the lifting process. The steel reinforcement for Bini's first dome was a series of circular concentric steel rods connected with steel chains (Fig. 02) and the concrete was kept in position with specially cut sections of galvanized chain link fence attached to the steel rods when the dome was fully inflated the bi-directional transverse chains would eventually resist the air-pressure from inside the fabric dome. Bini tested this system 'dry' without concrete to make sure of a smooth transition from flat to dome shape before the first lift. For the first dome concrete was poured at ground level with a variable thickness from the edge to the centre. After the air pressure had successfully lifted the dome using only a single fan, the texture of the concrete was cracked and crumbly and was re-compacted and smoothed by hand, using trowels. Bini himself admits that the original development of his construction process was empirical and with each prototype adjustments and innovations were made.

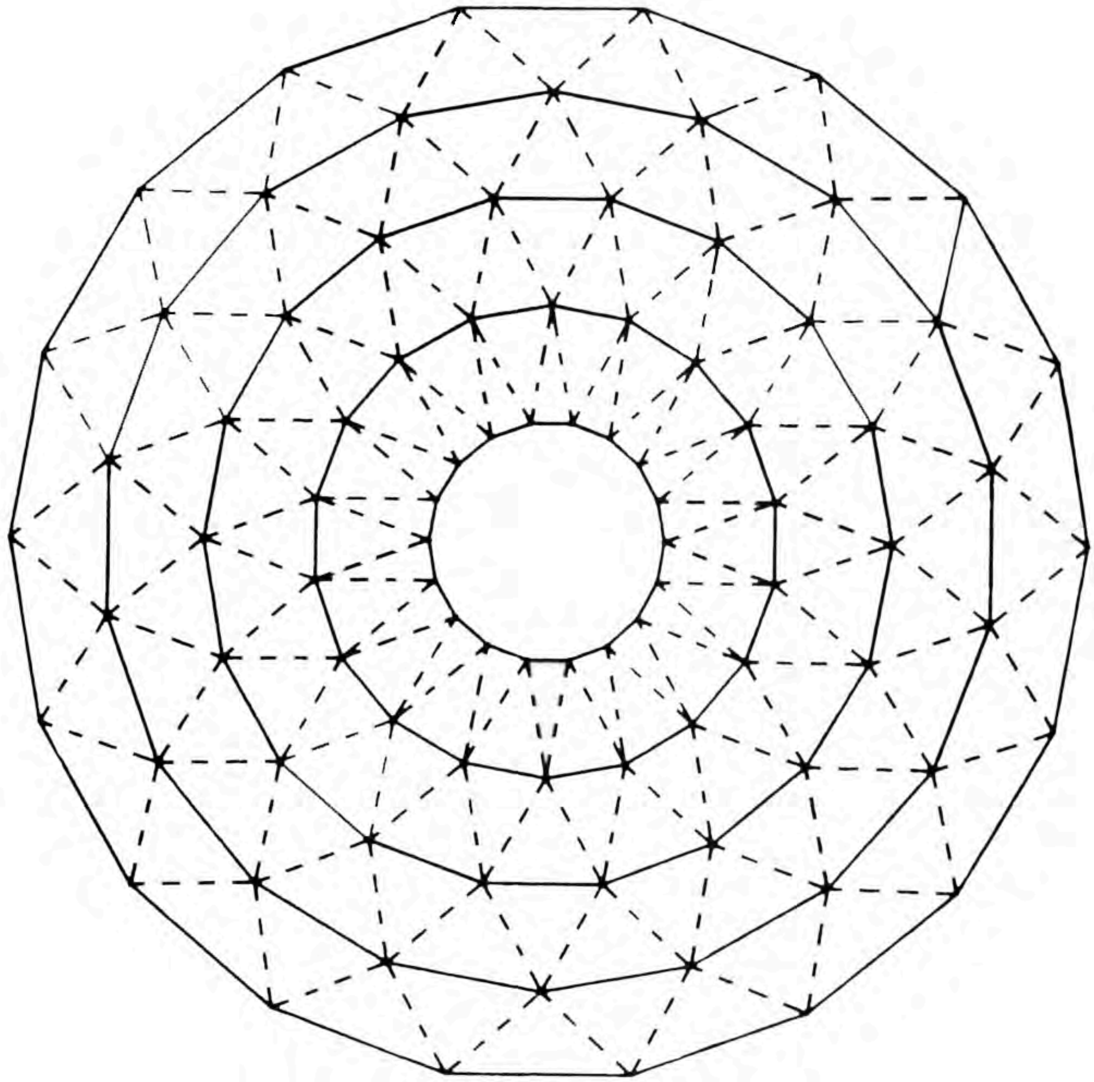

Figure 2. Architect, Dante Bini. Drawing showing the reinforcement layout of the Crespellano Binishell with the concentric circles indicating steel rods and the dotted radial elements are steel chains, 1964. Private archives of Dante Bini.

One of the major problems Bini experienced was the controlling of the concrete lifting process. For a 30 metre diameter dome of over 700 square metres, the pneumatic formwork has to lift approximately 200 tonnes of wet concrete using a fan-generated pressure of approximately 5 kPa. Photographs taken during the lifting of Bini's first 30 metre diameter dome at Castelfranco Emilia, illustrate how the unconstrained concrete bubbled and swayed during the inflation process. (Fig. 03) The first 30 metre dome (Fig. 04) was successful and still stands today, but Bini new that he needed to successfully industrialize or systematize his unique construction process for it to become a marketable product. Through another leap of imagination Bini had the idea to use a network of steel springs stretched flat across the circular base at tangents to the perimeter. (Fig. 05) These springs would contain steel reinforcement rods inside, fixed at the perimeter and overlapping at the centre. The springs would serve four purposes: Firstly to control the lifting of the concrete with their opposing force, secondly to house the reinforcement bars, thirdly to prevent the concrete slumping to the edges, and finally to introduce a degree of post-tension into the concrete once set. Another issue that Bini had encountered was the crumbling of the concrete during the lifting process and the need to re-consolidate. Bini had initially used local craftsmen to hand trowel the exterior, which was effective, but not systematic and labour intensive. The use of a second, external membrane was subsequently introduced, which as well creating a uniform outer skin finish, allowed a concrete vibrating machine to be run across the surface, post inflation. The mobile vibrating trolleys, which Bini also developed were hung from a central spigot at the pole of the dome and towed around the surface to reconsolidate the concrete around the steel springs and reinforcement rods.

Figure 3. Castelfranco Emilia, Italy. Architect, Dante Bini. The first 30 metre diameter Binishell during inflation, 1967. Private archives of Dante Bini.

Figure 4. Castelfranco Emilia, Italy. Architect, Dante Bini. The first 30 metre diameter Binishell before and after construction, 1967. Private archives of Dante Bini.

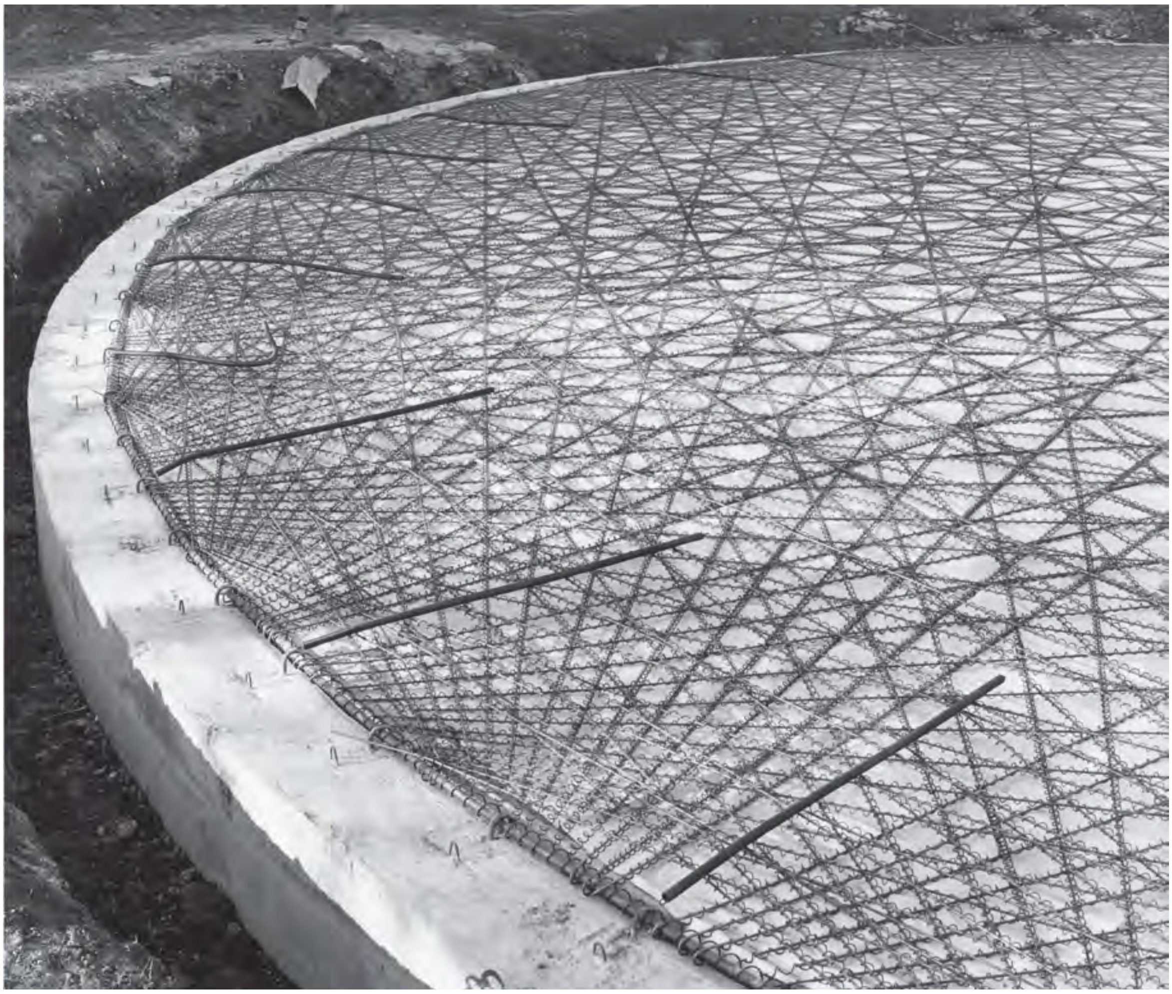

Figure 5. New South Wales, Australia. Architect, Dante Bini. Detail of spring network (with internal steel reinforcement bars), 1973. Photo: Max Dupain. Private archives of Dante Bini.

The engineering of the Binishell

> "Look, today I saw an amazing thing! If you were an engineer you would never have conceived of such nonsense"[ii]
>
> Mario Salvadori

In 1966 the structural engineer Mario Salvadori and professor of Civil Engineering and Architecture at Columbia University, New York was in touch with Dante Bini. Salvadori had read an article about Bini's first dome and invited him to New York to explain his process. Salvadori had himself; working with architect Elliot Noyes constructed a number of thin-shelled concrete buildings in 1954 using inflatable formwork. The process that Noyes and Salvadori used was based on an inflated formwork system devised by Wallace Neff[iii] in 1942. The Neff system differed insomuch as it employed an inflated static form, on which reinforcement is placed and then sprayed with concrete (Gunite). Salvadori's invitation was as much of a challenge to Bini whose process sounded unbelievable to him. After their initial meeting, Salvadori was invited to Italy to witness the construction of a Binishell with his own eyes. The demonstration was successful and Salvadori invited Bini to create a demonstration Binishell on the campus of Columbia in New York City, which was successfully realised in May 1967. (Fig. 06)

Figure 6. New York City. Architect, Dante Bini. Demonstration construction of a 15 metre diameter Binishell at Columbia University at the invitation of Mario Salvadori, 1967. Private archives of Dante Bini.

The New York demonstration was widely publicised including an appearance on the front page of the New York Times, which helped to globally promote the work of Dante Bini and the Binishell Company. The meeting with Mario Salvadori had been a challenge to Bini to reverse engineer his empirically developed structures and to provide proof of their engineered strength and characteristics. Following testing at the Institute of Construction, Turin Polytechnic under the supervision of Guido Oberti, Bini published a paper entitled 'A New Pneumatic Technique for the Construction of Thin Shells' as a part of the Proceedings of the 1st International Colloquium on Pneumatic Structures in May 1967.[iv] Simultaneously Mario Salvadori published 'Technical Problems in the Design and Construction of Thin Shells'[v] where he highlights the advantages of the Binishells system over the Neff system, which obviates the need for costly scaffolding required for spraying the concrete and replaces the more expensive Gunite with a lightweight concrete. Salvadori also details methods of dome analysis and design explaining that a better understanding of the structural properties and behaviour of such structures was critical to their wider adoption within the construction industry.

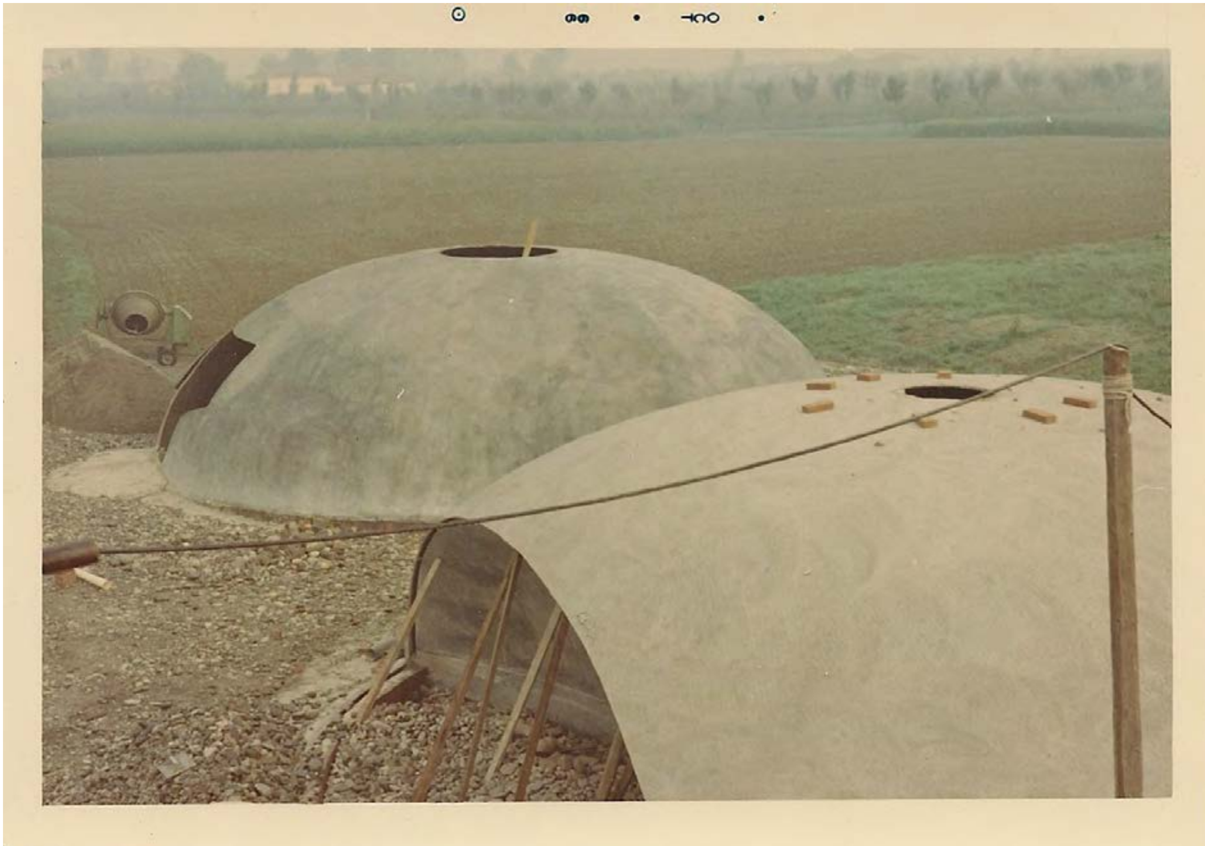

Figure 7. Castelfranco Emilia, Italy. Architect, Dante Bini. Early Binishells at the 'Mushroom Field' showing (foreground) a housing prototype developed for Liberia, 1966.

The experimental testing ground of the 'Mushroom Field'

In 2013 I accompanied Dante Bini to the site in Castelfranco Emilia, which had been nicknamed the 'Mushroom Field' by local farmers and visiting engineer Mario Salvadori. This former agricultural yard near Modena, surrounded by vineyards had been the test site for Bini during the inception and subsequent developments of his pneumatically lifted and formed thin shell reinforced concrete shells. Whilst the site has long since been abandoned, many of the original structural experiments still stand. Formerly used as industrial stores and even temporary housing, each structure tells a different story in relation to its geometry, casting process, reinforcement method, and material make-up. As a testing ground and showroom of his inventiveness, the *Mushroom Field* allowed Bini to experiment with different concrete mixes, plasticisers, retarders, aggregates and reinforcing systems all at 1:1. There was also a good deal of experimentation with the form of the shells themselves. For example, one elegant (and site-specific) configuration offers a prototype dwelling for Liberia, where a tangential slice of the dome is removed, rotated (180 degrees in plan) and then reconnected to form a concave and self-shading entrance. (Fig. 07) Another of the surviving 7 metre diameter domes is an insulated shell, where lightweight woodwool slabs are incorporated as a part of a permanent formwork. Whilst the woodwool slab has mostly rotted away, this idea of casting-in lightweight formers was to be repeated in one of Bini's later construction systems. In a search of Bini's personal archive, I could find only one documented example of a scale model (a pressurised elastic membrane at 1:10 scale), which was used to refine the cross-sectional profile of the Binishell. In the mid- to late-1960s, Bini was clearly able to marshal all the local craft skill required for the construction of these thin-shell reinforced concrete domes at a variety of different dimensions, but all at full scale. The site at Castelfranco Emilia afforded a unique workshop environment or test bed for the development of Dante Bini's ideas in way that parallel's the work of Pier Luigi Nervi and his invention and construction of the Ferro cement Pavilion at Magliana in Rome, 1945.[vi]

The Refining of the Binishell

"It is not just the physics that have to work in the successful launch of new construction technologies, it is also other, external factors … the metaphysics."
Dan Ptacek[1vii]

In one of his most successful projects, Dante Bini was employed by the Department of Education in New South Wales, Australia to deliver over 20 educational buildings under a very tight schedule and budget. Bini was contacted in 1971 and visited by a delegation from Australia who visited a number of Binishell structures across Italy including sports arenas and swimming pools. The tight timescale of the Australian projects was perfectly suited to the Bini methodology, and the result was an exemplary project, matching programmatic need to technological fix and spatial flexibility (circular, clear span, etc.) Given the imperative of construction speed and cost (allied to political promises), Bini, now well rehearsed with his unique technology of pneumatic formwork, standardised the diameters of the domes to 18 metre and 36 metre and successfully delivered the projects (in a variety of cosmetically different versions) on time and on budget. In order to facilitate the project, Bini clearly set out the Binishell construction process in a set of instructional documents that included diagrams of key details and was subsequently published[viii]. The construction of the Ashbury Public School administration building an 18 metre diameter dome new Sydney, NSW was recorded by the renowned Australian photographer Max Dupain and provides one of the most complete documents of the construction of a Binishell. (Fig. 08) Following the completion of the New South Wales (NSW) schools projects, the Concrete Institute of Australia and the NSW Public Works Department hosted a Bini-Shells Seminar[ix]. In a ten-page publication to accompany the event, diagrams, photographs and technical drawings illustrate the construction process, and finished buildings. The document includes drawings of two of Bini's key innovations, which enabled their construction; the mobile concrete vibration cart for concrete consolidation and the footing (or edge beam) detail[x]. (Fig. 09) This detail incorporates an ingenious 'figure of eight' profiled, pneumatic edge tubing. This tube is used during the pouring of the edge beam to produce a groove in the concrete foundation near the surface. The tube is latterly re-inflated in order to pneumatically anchor the pneumoform ground membrane during the lifting of the dome.

Figure 8. New South Wales, Australia. Architect, Dante Bini. Construction of Ashbury Public School administration building, 1973. Photographs: Max Dupain. Private archives of Dante Bini.

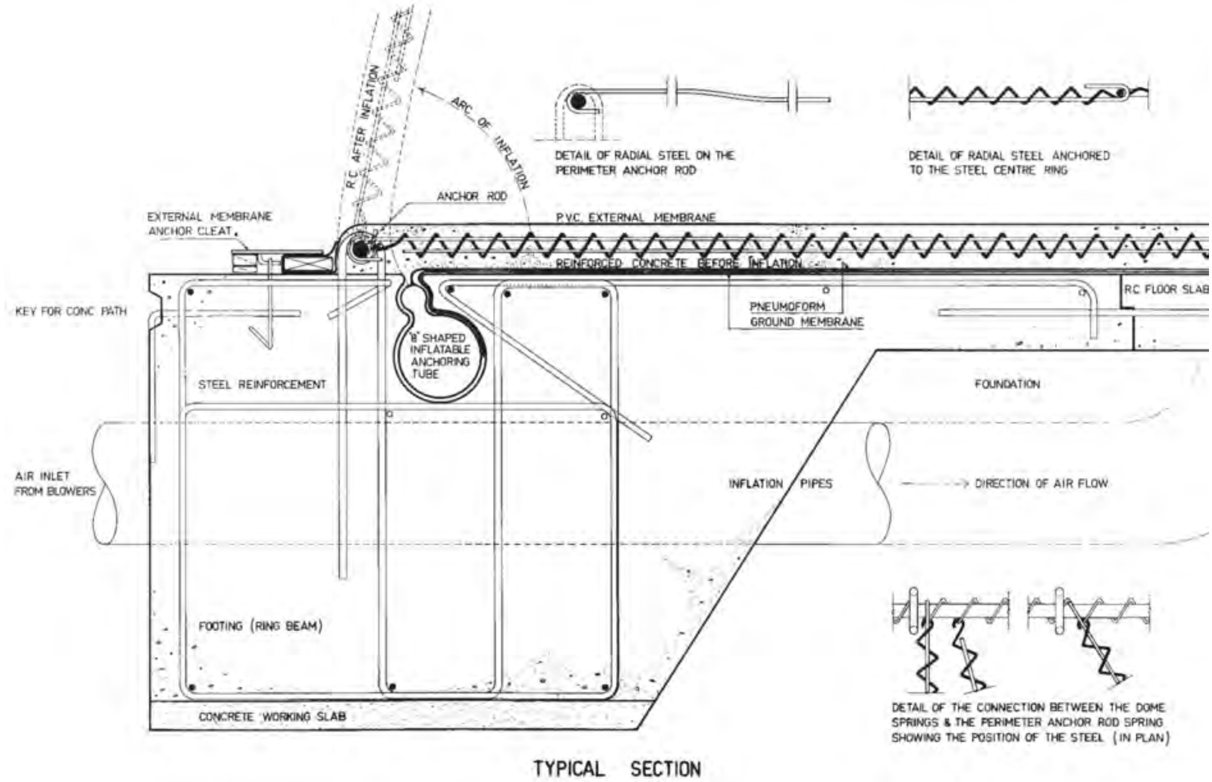

Figure 9. Architect, Dante Bini. Detail drawing of edge beam footing showing inflatable anchoring tube for pneumoform, 1974. Private archives of Dante Bini.

Whilst Bini had previously licensed his patented technology (with mixed results), it is arguable that his presence on the ground as the designer/contractor was a large contributory factor in the success of the New South Wales projects. The Binishell system is a patented technology and as such the construction methodology is clearly expressed and its products eminently repeatable, but it is perhaps Bini's role as 'craft contractor' in the manner of his great inspiration Pier Luigi Nervi, which might be seen to be most successful. The Binishell technology was licensed in the UK at the time as Parashell and was used to create what was thought to be the only extant example of a Binishell in the UK, Michael Godwin's (Godwin & Cowper) 'Edinburgh Dome'[xi], built in Malvern in 1977. Following a visit to Italy in 1974 to view a number of Binishell projects, Michael Godwin used Bini's system to create a 36 metre diameter school sports hall for Malvern Girls College, which was officially opened on May 4th 1978 by Prince Philip, the Duke of Edinburgh. The entire dome is raised on a series of eight concrete pilotis to provide natural light reflected from the surrounding pool. So in this case the dome forms a 'lid' atop large columns with the elevated ring-beam holding the dome in place. In May 2009 the 'Edinburgh Dome' was given a Grade II listing in recognition of its rare (and seemingly unique in the UK) construction method and quality of architectural execution. I have recently discovered that there is in fact another Parashell dome still in existence at Mildenhall in Suffolk and I am currently in contact with the original job architect Simon Conolly to ascertain more details of it's construction.

In a conference paper from 1993[xii], Bini reported that between 1970 and 1990 over 1,600 Binishells were successfully constructed across 23 countries, three of which subsequently suffered failures[xiii] and were demolished or rebuilt.

The Proliferation of Bini Systems

During his time in Australia Bini also developed and prototyped a number of other structural systems. The Minishell system can be viewed as a development of the original Binishell patent and is designed to produce small, 8 metre x 8 metre low-cost, square or octagonal-based, monolithic, reinforced concrete shell structures, provided with openings at the corners which result from the construction process. Bini had observed the difficulties (especially with the large 36 metre diameter domes) of maneuvering, positioning, anchoring and folding of the inflatable membrane. The largest membranes (for a 36 metre diameter Binishell) had a surface area of 1000 square metres and could weigh over 1500 kg. The 8 metre x 8 metre Minishell system was designed to use less than 5 cubic metres of concrete and could be formed (excluding site preparation and foundation) in only 30 minutes. Interestingly, the protruding upturned edges formed around the openings during inflation help to create a raised 'lip' around the edge of the openings, which acts to stiffen the arch formed openings. Several tourist villages in both Australia and Italy were built using this system including Cairns in Queensland, Australia, of which Bini designed and oversaw construction of and was completed in 1980.

Another system prototyped in Australia although not further developed, was Binix. (Fig. 10) Binix was not a shell structure, but a ribbed (or lattice) dome structure, which employed a system of prefabricated lightweight polystyrene 'void-formers' laid flat in a diagrid across a membrane. A grid of steel reinforcement was then laid in the channels between the chamfered polystyrene forms, which were then filled with concrete. The membrane was then inflated to lift the reinforced concrete lattice dome, which, when the formers were removed was more redolent of a geodesic frame. Bini notes, that "The only problem experienced during the construction of the prototype was the difficulty in re-compacting and vibrating concrete inside the raised form network."[xiv] Bini claimed that the Binix patented method of construction could produce hexagonal-based monolithic reinforced concrete framed dome structures with spans of up to 100 metres[xv]. Bini also adds that the Binix system "…had even greater potential than the Binishell itself, because in addition to its aesthetic appeal, it would provide the necessary thickness of steel cover for reinforced concrete required by building codes across the world."[xvi]

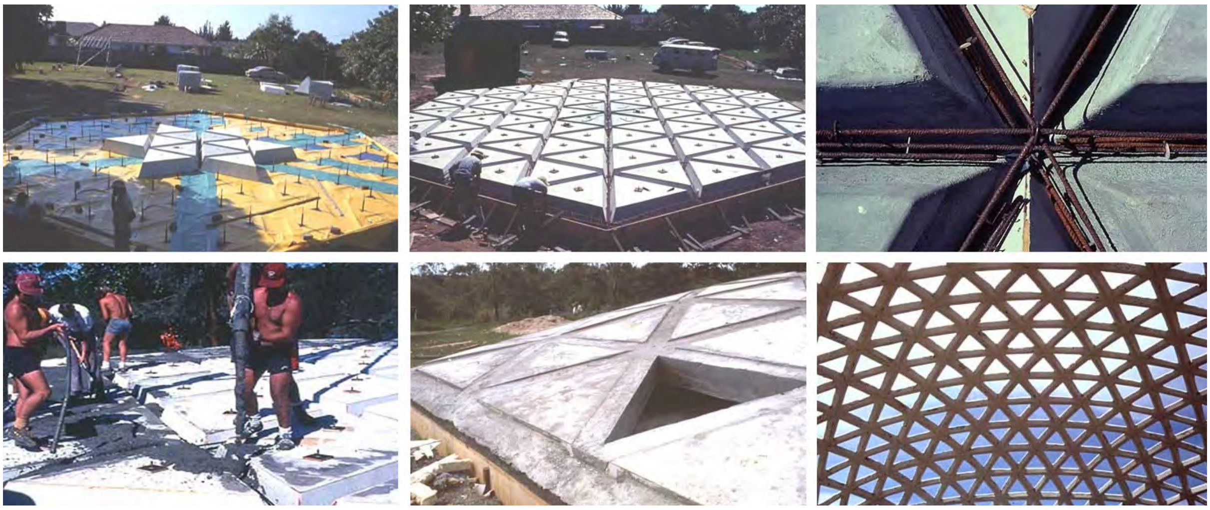

Figure 10. New South Wales, Australia. Architect, Dante Bini. Sequence showing the only built prototype of the Binix system, 1976. Private archives of Dante Bini.

By the 1980s Bini was starting to explore fabric-covered space-frames, and in a successful collaboration with the Gruppo Dioguardi construction company he realised a number of these structures, notably for FIFA's Italia 90 World Cup. This new construction system was called Binistar (Fig. 11) and it employed an air-filled membrane to lift the structure, which was a space-frame composed of extendable strut members that would lock together when the fabric was fully inflated. The PVC membrane used for the structural erection process was then left in place as the building skin. This process of 'building with air' (which became the English title of his memoir of his life in architecture and construction) became the main focus of his subsequent research projects.

Through his built work and contributions to conferences and congresses, Bini was increasingly invited to act as a specialist construction consultant. One such invitation took him to Japan to work with the Shimuzu Corporation. Amongst the many highly speculative projects Bini worked on with Shimuzu was his contribution to TRY 2004, a prototypical megastructure designed for one million inhabitants at Tokyo Bay. The proposed structure was a pyramidal tower of 2004 metres high and one of the most difficult technical challenges was how to build such a structure, which Bini answered with giant pneumoform spherical forms that would use compressed air to assemble the giant modules. At a more modest scale was the Air Lift-Up System[xvii] (or ALU) (Fig. 12) where Bini in collaboration with Shimuzu developed an idea for a multi-storey construction system that used air (in both positive and negative pressure) to push up and pull up concrete slabs (cast in situ) around a series of columns.

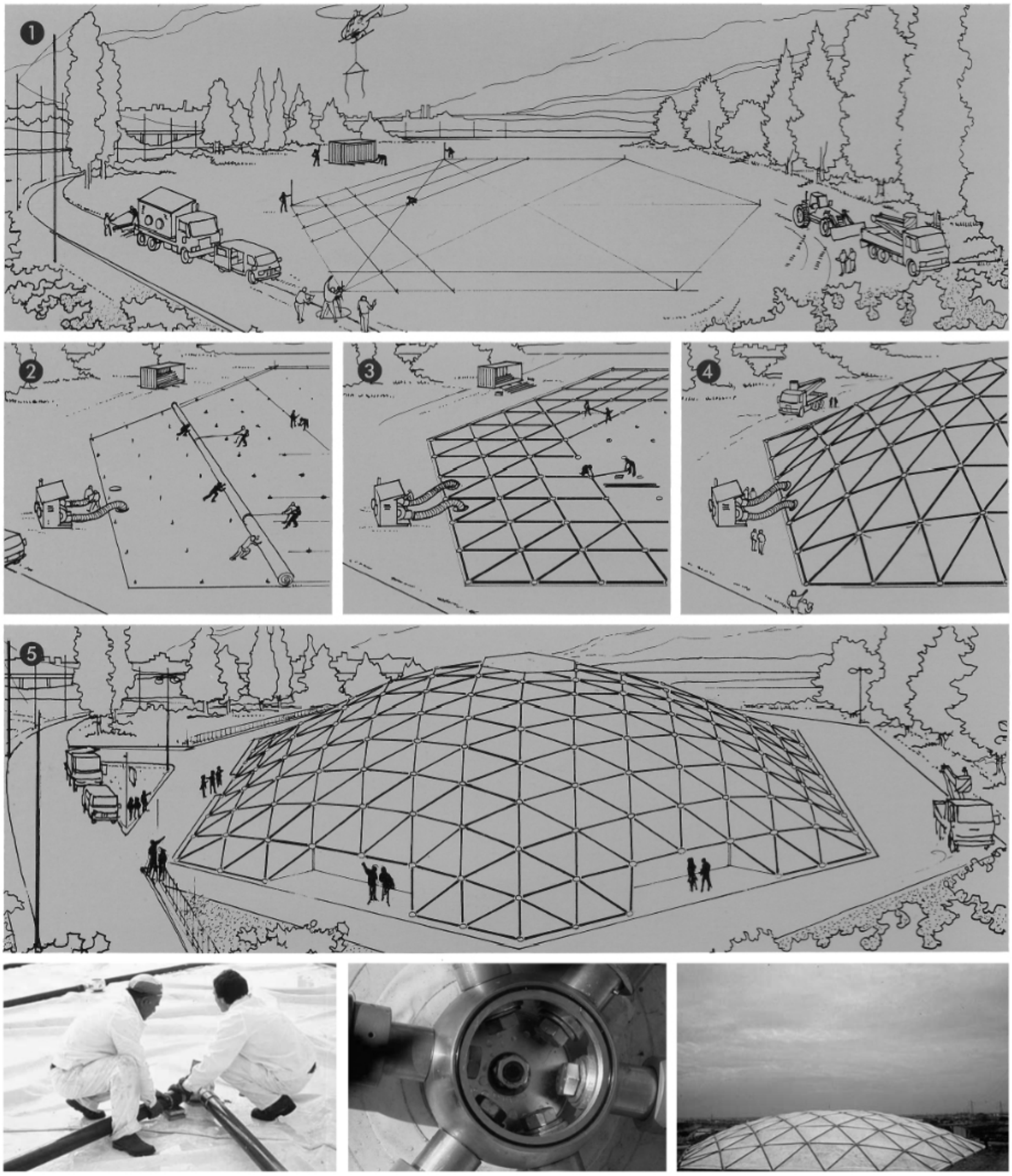

Figure 11. Architect, Dante Bini. Assembly sequence of the Binistar system, with photographs of system assembly and fabric connections to external frame, 1982. Private archives of Dante Bini.

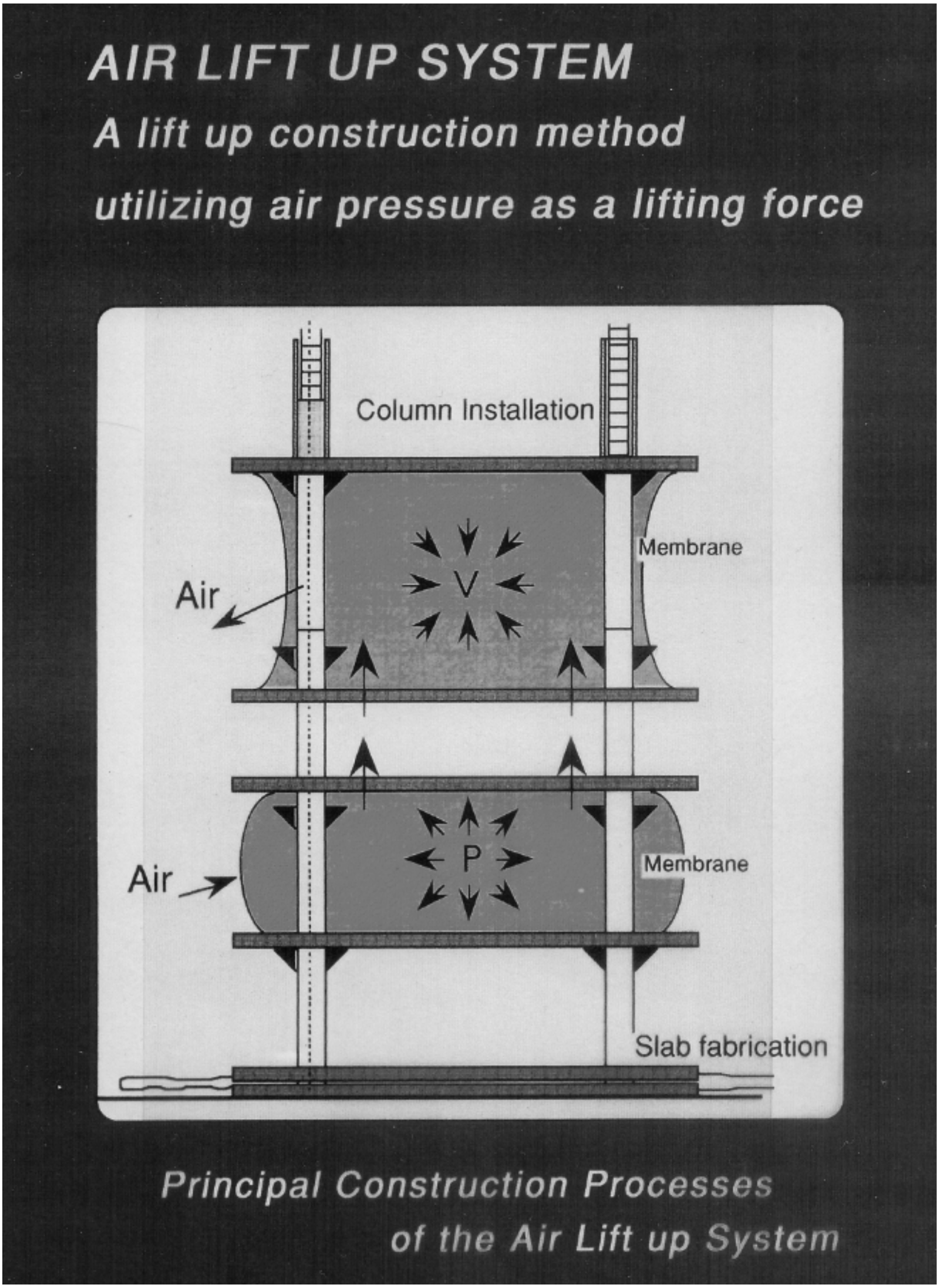

Figure 12. Architect, Dante Bini. Air Lift-Up System developed with Shimuzu, 1982. Private archives of Dante Bini.

Conclusion

The work of architect Dante Bini and in particular his Binishell system for lightweight 'domed' concrete shells developed in the early 1960s was technologically inventive, but remained largely a niche construction product looking for a client. It was arguably the exposure of Bini's ideas following his demonstration Binishell at Columbia University, New York that both legitimised this new technology and launched Bini's career. Throughout that career as variously an architect, inventor and builder Dante Bini has utilised the inexpensive, safe and ubiquitous material of air as a motive force and forming medium. Common to almost all his projects the use of differential air pressure as a means to lift and form heavy materials like concrete embodies an approach, which is both influenced by the great concrete craftsman architect Pier Luigi Nervi and simultaneously the "doing more with less" philosophy of Richard Buckminster Fuller.

The unique test bed of the 'Mushroom Field' at Castelfranco Emilia afforded Bini a series of demonstrable building systems and products, which although experimental, did not simply remain ideas on the drawing board. His empirical testing of both the properties and qualities of the new Binishell forms at the start of 1960's can find a parallel in the sheet metal experiments of French architect Jean Prouvé. Prouvé's work was also an exercise in material exploration and with the seminal work at his Maxéville factory he was both the designer and fabricator of architectural artefacts from furniture to prefabricated buildings. There are other parallels with Prouvé to whom the construction process of any given project was an integral part of the design. Bini was, and continues to be fascinated by what he calls Construction Automation and sees one of his key jobs as a systems designer to make the system easily (or more easily) buildable. With renewed interest in Fabric Formwork of which we can include Bini as a pioneer, a wider evaluation of his work and perhaps more specifically his working method is long overdue.[xviii]

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