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THE INDUSTRIALIZATION OF CONSTRUCTION IN THE SECOND HALF OF THE XX CENTURY

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Cover illustration: MBM factory in Trezzano sul Naviglio (Milan), Italy.

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EDITORIAL

THE GREAT ILLUSION. ORIGINS, PROSPECTS, AND DECLINE OF RESEARCH ON BUILDING INDUSTRIALIZATION IN ITALY

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I recall construction sites in Rome during the early 1950s: the post-war reconstruction era and the expansive building efforts that would transform the city. My father often took me along during his inspections as the site director for the *Istituto Autonomo Case Popolari* (former IACP and now ATER - *Azienda Territoriale per l'Edilizia Residenziale*). I was struck by the sight of a forest of timber scaffolding where countless workers diligently labored, performing all tasks manually.

Indeed, in Italy, during the post-war period and well into the early 1950s, mechanization in construction was either absent or extremely limited. These limitations were partly due to the fact that only a few construction sites were connected to the electrical grid. Most workers were unskilled laborers recruited from the massive migration waves from southern Italy and rural areas, often awaiting further relocation to industrial cities in the north. To better understand those times for those who did not live through them, I recommend watching (or revisiting) Luchino Visconti's movie masterpiece, *Rocco e i suoi fratelli*.

Master builders were generally highly skilled masons who typically worked alongside a laborer. The latter assisted with utmost respect and obedience in all tasks, from transporting materials to handing them over at the right moment and helping with their installation. With the emerging diffusion of reinforced concrete, specialized roles such as cement workers, rebar installers, and formwork carpenters began to form. Scaffolding, however, was still entirely wooden, usually handhewn.

In the Architectural and Building Design (*Architettura Tecnica*) courses within the engineering faculties, these "traditional" construction techniques were presented and taught even at high-level education. In this regard, it is valuable to consult Carlo Roccatelli's two-volume work *Elementi delle Costruzioni Civili* (1950), which followed Giovanbattista Milani's seminal manuals (1930-40).

However, studies on applying the principles and techniques of the Industrial Revolution – focusing on mechanized serial production – to construction had already begun outside Italy.

The research started much earlier in Weimar, during the post-World War I period in France and Germany. It was under the direction of prominent architects of the Modern Movement that the key conceptual lines of European construction industrialization were defined (the United States represents a separate historical narrative).

Le Corbusier's *Maison Citrohan*, designed in 1922 and realized in 1927 for the *Stuttgart Werkbund*, represents the archetype of a serial model conceived for industrial production. A few years later, in 1932, Beaudoin and Lods realized an extraordinary social housing project in Drancy, near Paris. This project was entirely executed using a serial prefabrication process involving reinforced concrete panels on a steel structure – a prototype of subsequent industrialized systems based on large panels. France was thus both conceptually and technically prepared for the extensive post-war reconstruction and subsequent intense development of large-scale housing projects, known as *Grands Ensembles*. These developments were based on specific building typologies that could be replicated with components industrially produced in factories and assembled onsite. This approach was defined as "*closed-cycle industrialization*" and was often referred to as "*heavy pre-*

fabrication" due to the use of large reinforced concrete panels.

Simultaneously, in Weimar, the Bauhaus was advancing the design of building components, often in steel or wood, focusing on developing the "universal joint". Notable here is the work of Wachsman, who later furthered these concepts in the United States. The rise of Nazism disrupted this research network, dispersing many scholars, several of whom ran away to Great Britain. It was there, in the post-war period, that systems based on the industrial prefabrication of "*lightweight components*" emerged. These systems were used in reconstruction efforts and the development of New Towns. Initially tied to the assembly of specific building types, they soon evolved to include components designed to be bought by catalog. In 1955, the CLASP (*Consortium of Local Authorities Special Programme*) was established in the UK to develop a system for school construction. This initiative was quickly followed by several similar consortia, each proposing unique systems. Generally, these systems relied on steel structural frames combined with reinforced concrete slabs and lightweight envelopes produced by various industrial factories. This laid the groundwork for what would later be known as "*open industrialization*".

By the late 1950s, Italian construction sites had begun adopting more rationalized production processes. Forward-thinking builders sought more efficient and economical alternatives to traditional techniques. Typically skeptical of research (as they remain today), especially academic research, Italian builders closely observed developments abroad, selectively importing innovations they deemed valuable. I recall many Italian entrepreneurs traveling to France, returning in awe of the newly acquired construction technologies. This was the era of on-site industrialization, marked by the widespread adoption of tunnel formworks and systems such as "*banches et tables*", which allowed for rapid construction at the expense of typological and performance limitations. Some builders pursued independent research into automated formwork systems, such as those developed by Grandi Lavori S.p.A. in Bologna under the guidance of Chief Executive Officer (CEO) Mario Tamburini. By the early 1960s, Italian industrialists began importing French patents for closed-cycle industrial prefabrication and established significant manufacturing facilities, particularly in Northern Italy – among the first being the Marcegaglia MBM factory.

Within this technical and cultural context, and with these necessary forewords, the 1960s witnessed the birth of Italian research on building industrialization in some universities. The aspiration was to profoundly renew construction practices, blending designers' compositional freedom with the industry's productive capacity.

Numerous critiques emerged regarding the approach of industrialization through predefined building models. The primary criticism was conceptual, focusing on the impact these models – albeit of high design quality – would have on the architecture of cities, which risked being reduced to monotonous repetitions of a few identical types. Another significant criticism concerned the industrial production process, which required large prefabrication plants concentrated in a few strategic locations and operating under oligopolistic conditions. This approach contrasted sharply with the vision of a distributed network of small and medium-sized mutually complementary industries, which appeared to be the natural evolution of the construction sector.

Other scholars firmly believed that the sector's development should rely on a widespread industrialization process based on the serial production of "open-cycle" components – an approach also referred to as "*component-based industrialization*". This principle involved producing building components independently of the design of the architectural organism in which they would be integrated. Consequently, the process was envisioned to occur on two distinct but closely integrated levels: the design of components and the architectural design of the whole building. Essential features linking these two levels were modular dimensional coordination, joint coordination, and the components' catalog.

The two founding principles of this approach were: firstly, the diffusion of many small to medium-sized industries across the territory capable of innovating and improving through dynamic competition; secondly, the absolute freedom for designers to create architectural organisms supported by the ability to select industrialized components freely. Due to their "small" dimensions, these components would play a compositional role in the project akin to bricks in architectural history. Therefore, the production of components could begin industrially, selected by designers, offered on the open market as construction products, and purchased through the catalog.

Criticism of this approach was not absent. For example, Pierluigi Spadolini, despite recognizing the intellectual merit of this process, expressed deep doubts about the actual "openness" of the architectural outcomes. He argued that these components, as defined, were far more complex than traditional bricks and thus carried substantial semantic implications that could undermine the "compositional freedom" of architectural design. In response to such critiques, research focused on two primary areas: the deepening of techniques related to modular dimensional coordination and joint design – an area primarily rooted in theoretical elaboration – and experimentation with the design of open-cycle components.

The leading proponents and initiators of these research approaches in Italy included the following professors: Giuseppe Ciribini (1913-1990) at the *Politecnico di Milano* (from 1968 in Torino), Pierluigi Spadolini (1922-2000) at the *Facoltà di Architettura* in Florence, Enrico Mandolesi (1924-2014) at the *Facoltà di Ingegnaria* in Cagliari (from 1971 in Rome), and Marcello Grisotti (1919-2012) at the *Facoltà di Ingegneria* in Bari (later in Milan). These figures became essential references for research in this field.

Giuseppe Ciribini was the philosopher of this movement. In addition to his studies on the relationship between human sciences and architecture, he was the leading theorist of building standardization and modular coordination as foundational elements of industrialization. At the *Politecnico di Milano*, and later during the 1970s and 1980s, his work was complemented by Pietro Natale Maggi, a distinguished scholar of the construction process, design methodology, and work ergonomics – essential prerequisites for defining the building industrialization process.

Pierluigi Spadolini, an architect who also practiced as a well-known yacht interior designer, was interested in industrialized production, focusing mainly on component design. He was also a top-level consultant for state-owned Italstat (*Società Italiana per le Infrastrutture e l'Assetto del Territorio S.p.A.*) and a close friend of its president, Ettore Bernabei. In this role, he was pivotal in implementing the nationwide program for post offices (at least one in every Italian municipality), designing the external shell components, and giving the plan of these buildings their characteristic stamp-like shape.

Grisotti and, even more so, Mandolesi were holistic architectural designers. This feature was evident in how they approached research on building industrialization through components. Mandolesi, in particular, stood out for his pragmatism and exceptional dynamism. Alongside Grisotti, he revolutionized the historical teaching of Architectural and Building Design, a fundamental discipline in building engineering faculties. Professionally, in collaboration with Marcello Grisotti, Federico Gorio, and Achille Petrignani, Mandolesi designed the experimental CECA (*Comunità Europea del Carbone e dell'Acciaio*) neighborhood in Piombino for Italedil (*Italiana di Edilizia Industrializzata S.p.A.*), a controlled branch of Italstat. This project served as the basis for his highly rationalized approach to construction sites, which he later carried into research on building components.

I first met Mandolesi in 1970 when he was appointed full professor of Architectural and Building Design at the *Facoltà di Ingegneria* in Rome. At that time, he was again researching for Italedil. This time, he was involved in designing open-cycle steel components for residential buildings and invited me to assist him. He transformed his studio and the entire villa where he lived into a laboratory for experimental models, both at scale and full size (Fig. 1).

The applied research unfolded in several phases: conceptual development of components, detailed morphological and dimensional development, and modeling with wooden prototypes. The geometric design focused on structural elements, cross-braced floor slabs to be assembled on-site, vertical partition elements (walls and doors), vertical closures, and external frames. All components were to be made of steel, dimensionally

Fig. 1. *Italedil research project. Study for including of steel structures and construction elements in the open-cycle building industrialization process.*

coordinated, and pending technological and performance verification in workshops and laboratories using real materials. I vividly recall the complexity of certain elements, such as the beam-column joint, which was also prototyped in steel for various structural profiles (Fig. 2).

Mandolesi devised a full-scale model he dubbed "*visual netting*" to better experiment with grid systems in modular building design. It consisted of a set of 3-meter-long interlaced metal tubes spaced 10 cm apart, half of which were painted longitudinally. By rotating them, the modular reference lines highlighted in red could be used to verify the position of components on a full scale accurately.

The Italedil research project concluded in the early mid-1970s. Its studies were acquired by IpiSystem firm, a company owned by Italedil, with a prefabrication facility for "closed-cycle" steel systems for residential buildings and schools in Pennabilli; in the Marche region. Unfortunately, from then on, the experimentation with prototypes never advanced. Was the system too complex? Did its "open-cycle" component nature cause concern? Or was it deemed too costly to implement? Apparently, the times were not yet ready (and perhaps never would be) (Fig. 3).

By the mid-1970s, Tecnocasa S.p.A. was established in L'Aquila. The company, with shareholders including IMI (*Istituto Mobiliare Italiano*), Montedison, Italstat,

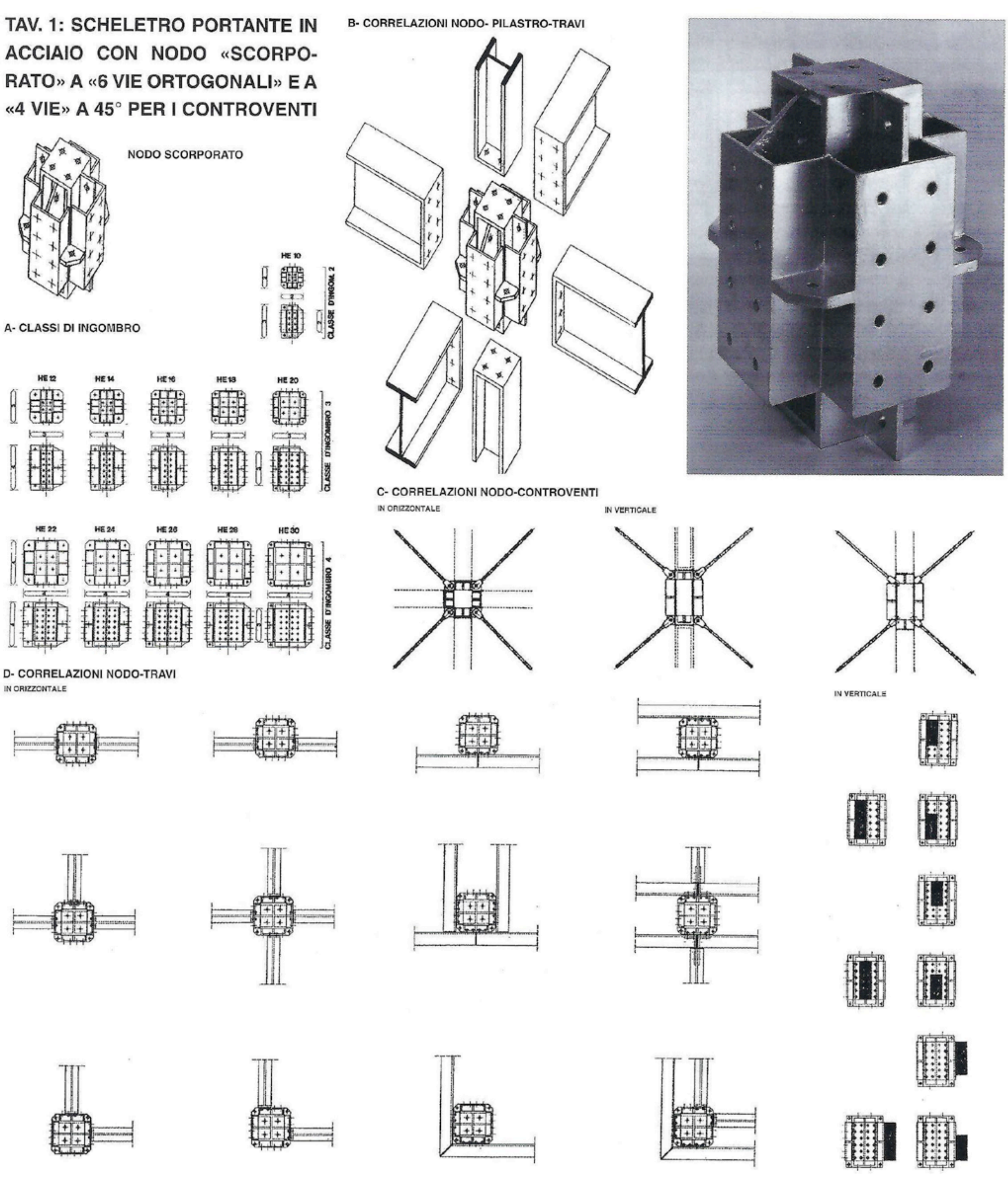

Fig. 2. *Italedil research project. Modular joints for steel load-bearing frame structures.*

and SIR (*Società Italiana Resine*), was a research entity dedicated to promoting and experimenting with new methods and models for industrialized construction. A generational shift saw the coordination of research activities handed over to a group of (then) young researchers active in the field, who had been mentored by the aforementioned "Great Masters", particularly Ciribini and Spadolini. This group included Nicola Sinopoli, Beppe Turchini, Ettore Zambelli, Aldo Norsa, and Marco Simonazzi, who, in various ways, became essential

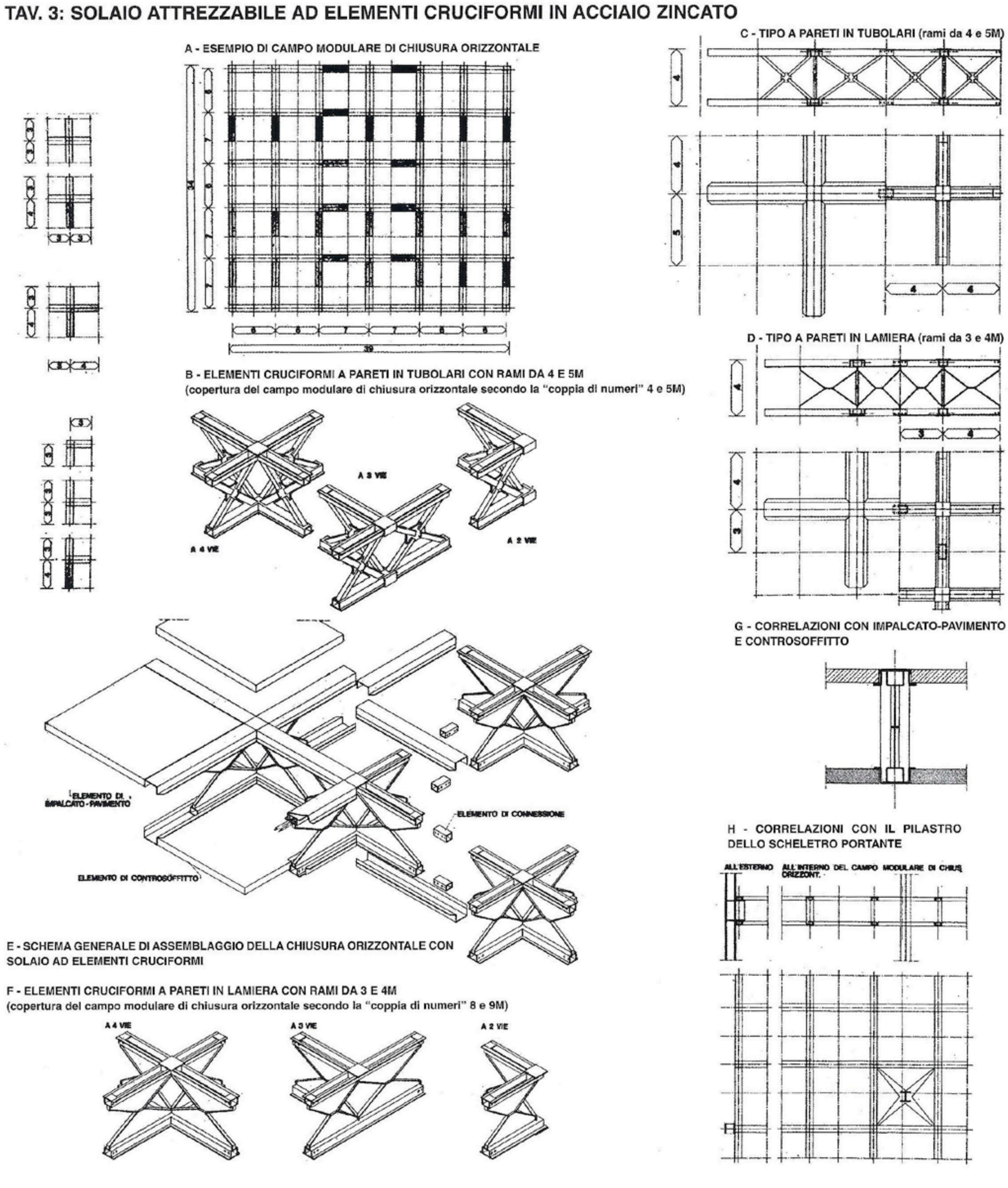

Fig. 3. *Italedil research project. Steel open cycle components for technical installation equipped floors.*

in developing and implementing the teachings of their mentors.

At Tecnocasa, fundamental studies were conducted on several topics, including the construction process – an innovative topic at the time –, the modularization of industrialized "open-cycle" components and technical performance standards. I participated with Mandolesi in a Tecnocasa research project to develop an open system for residential construction. Mandolesi's undeniable creativity in typology and architectural composition was ev-

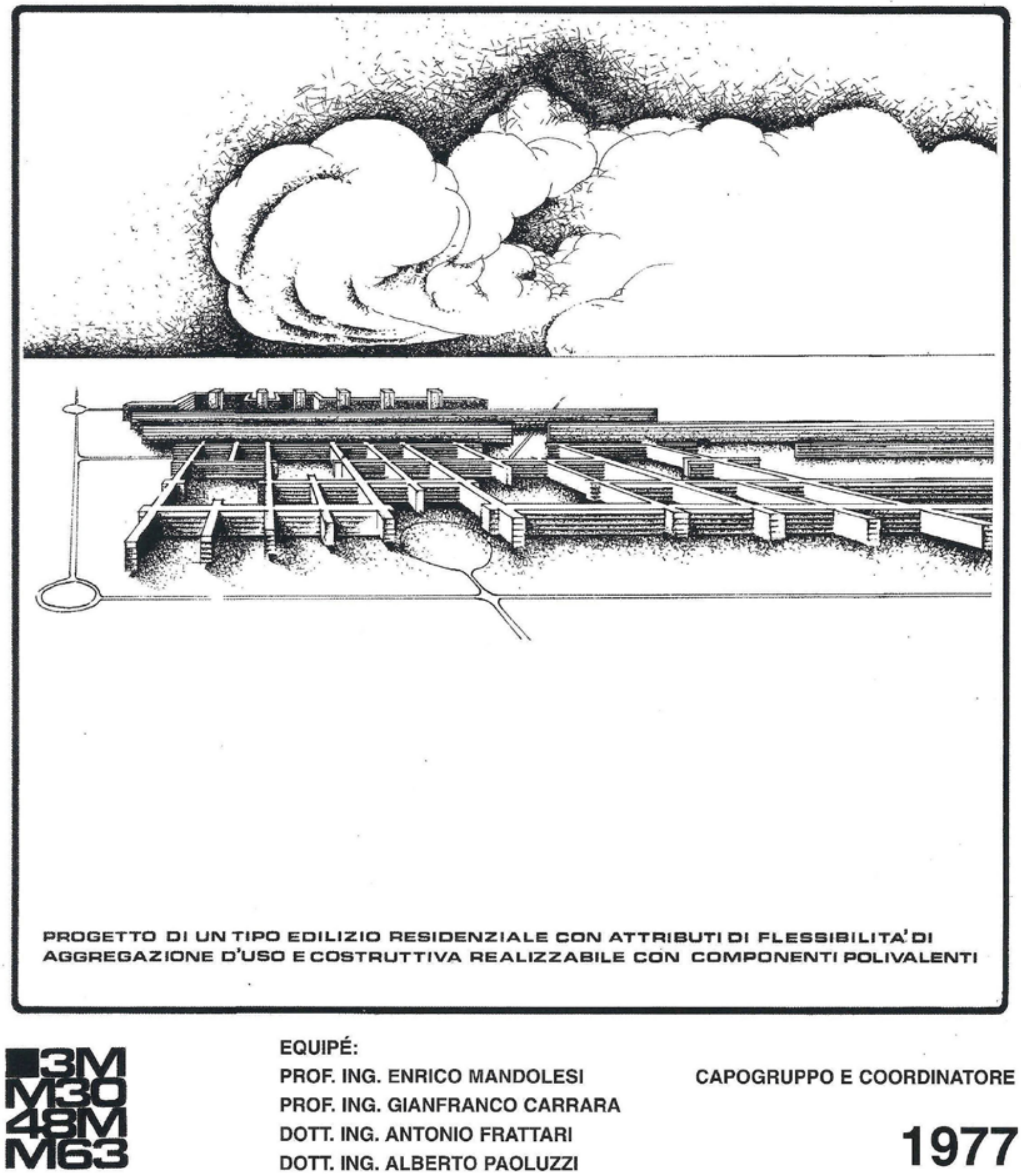

Fig. 4. *Tecnocasa research project. Design of a residential building typology with features of flexibility of use and construction aggregation realizable with multifunctional components.*

ident in the variety of housing schemes that could be assembled into numerous building types. These types were constructed using a reduced set of cataloged components intended for industrial production (Fig. 4).

However, some aspects of the project left me uneasy. The combinatory repetition in assembling components across various housing solutions seemed at odds with the design methods we used then. These methods relied solely on manual drafting on tracing paper, using pencils, and then redrawing with ink. I felt there had to be a more effective way to explore the compositional potential of combinability, and I saw the solution in computers – though, in the mid-1970s, the idea of computers as tools for architecture was still quite futuristic. Thus, I began experimenting with computational graphics at the *Facoltà di Ingegneria* at the *Sapienza Università di Roma*, working with Alberto Paoluzzi, a young graduate in Civil Engineering (later a full professor of Computer Graphics at *Università degli Studi Roma Tre*). Together and with a small group of enthusiastic Italian and international researchers, we entered the international world of research for the first time.

Another unresolved issue concerned the systemic relationship between the static and energy performance of

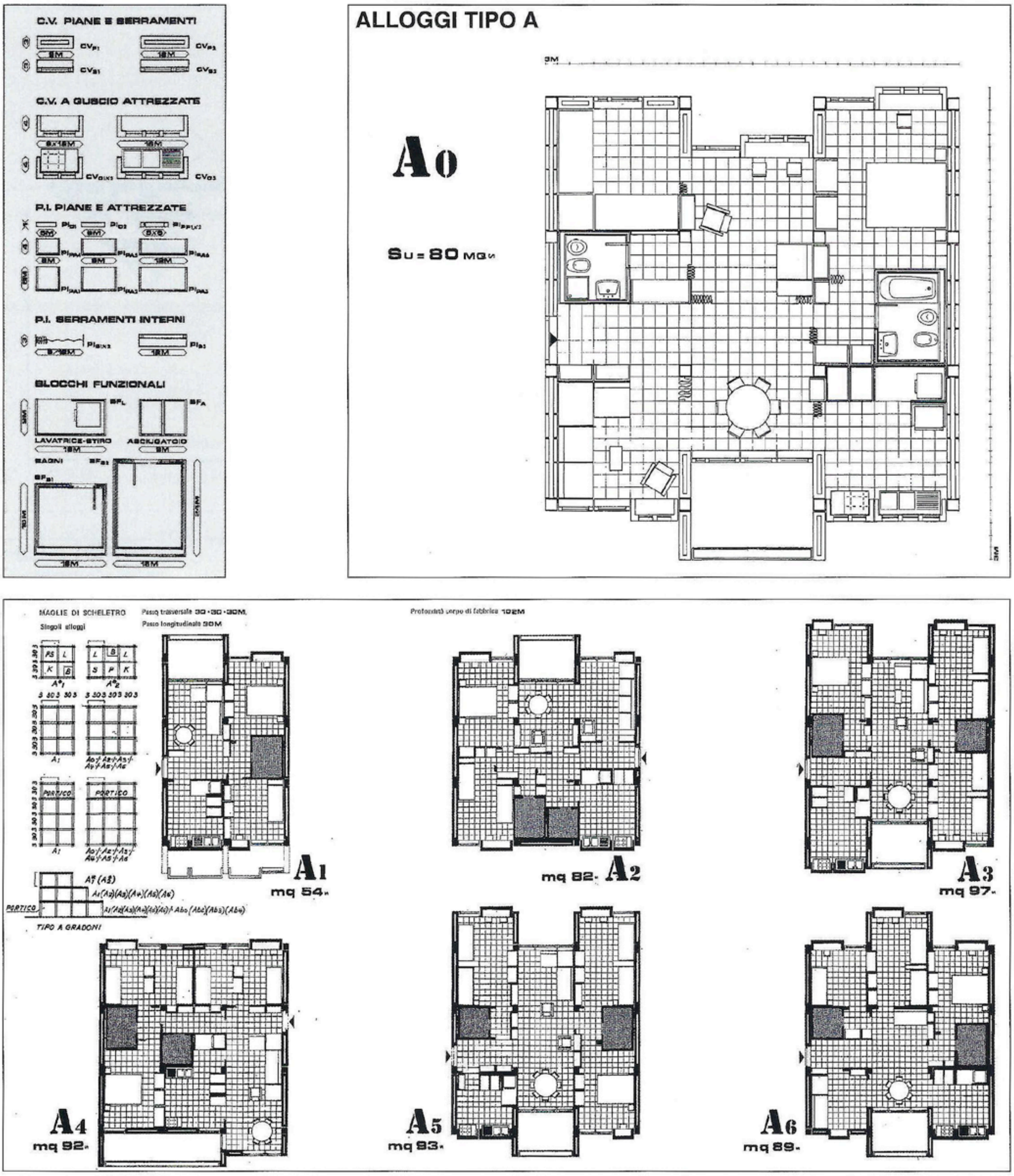

Fig. 5. *Tecnocasa research project. One of the several layout diagrams analyzing different aggregation possibilities of housing units with various sizes based on a dimensional coordination modular grid.*

individual components and the overall performance of the building assembled from these components. Paoluzzi and I initiated research on this topic – a journey that would take me far, encompassing numerous re-evaluations, changes in direction, and dead ends, but also significant successes and recognition (mainly on the international stage, validating the adage, *nemo propheta in patria*) (Figs. 5-6).

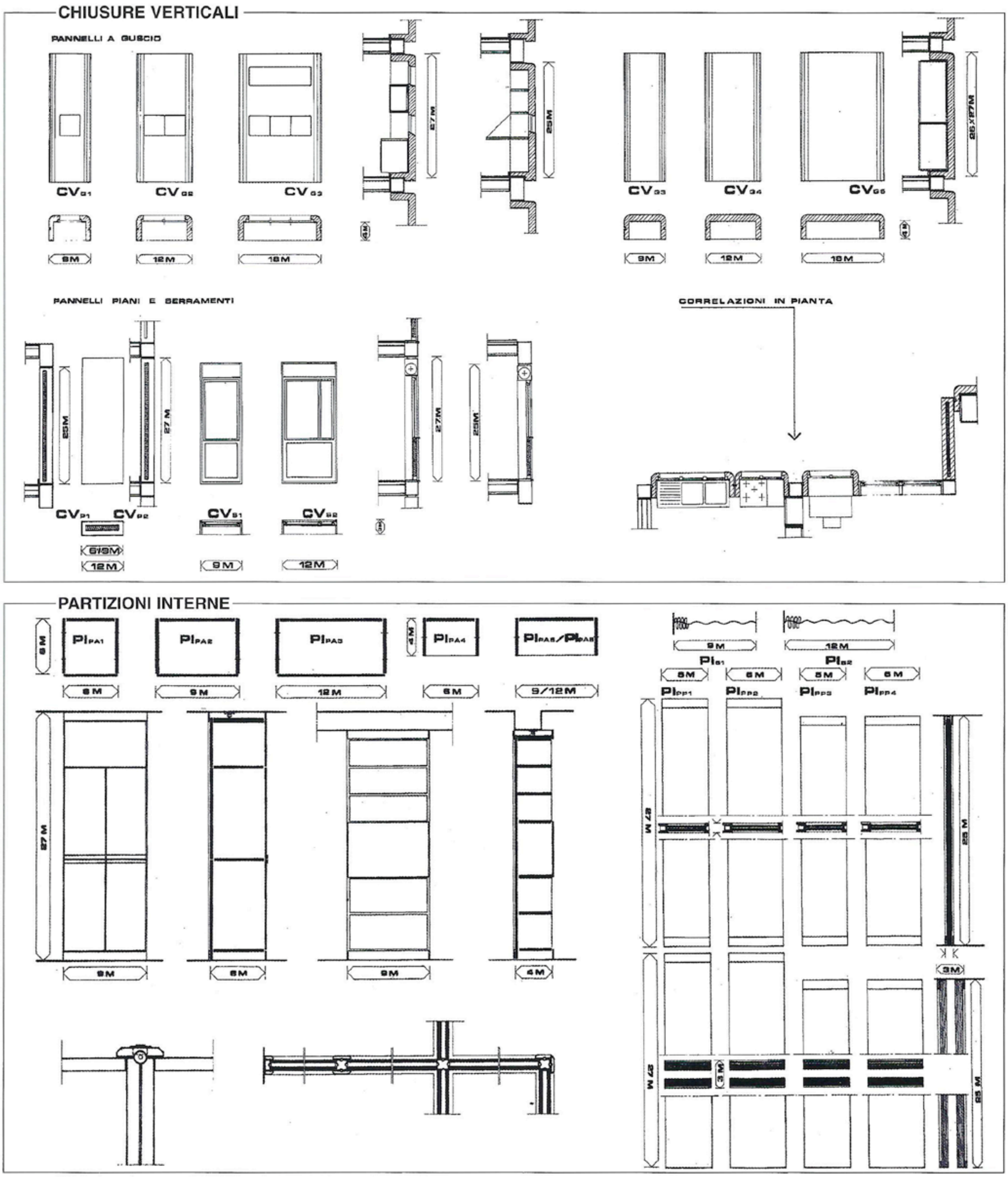

Fig. 6. *Tecnocasa research project. Prefabricated components for vertical closures and internal partitions.*

The outcomes of the Tecnocasa studies were documented in a series of publications. However, no experimental implementation or realization occurred, and the company eventually ceased its activities. Nonetheless, with the relocation of the Tecnocasa researchers to Bologna, the group became the foundation for the Emilia-Romagna Regional Technical Standards Research Group, directed by Nicola Sinopoli with contributions from the

ANIACAP Group (*Associazione Nazionale Istituti Autonomi per le Case Popolari*), led by Elio Piroddi. These studies soon became the benchmark for Italian building regulations.

In the early 1980s, many of us joined the CER (*Comitato per l'Edilizia Residenziale*) under the Ministry of Public Works. We worked on an experimental program for residential construction, coordinated with remarkable intelligence and competence by Massimo Bilò. This program was developed in response to Italian Law No. 94/82, which aimed to foster experimental residential projects in various parts of Italy, emphasizing advanced technological innovation.

The program became a platform for exchanging and applying theories and technological innovations developed through industrial research. However, only a small number of the projects conceived within the program's broad conceptual framework were realized – and even those were delayed for long periods.

Rather than housing, the program primarily produced valuable applied research studies, many of which remain relevant today. Unfortunately, most of these studies were never applied in practice. A wealth of technical and scientific proposals and documents emerged from the program, significantly contributing to an updated building design and production culture. These contributions were incredibly influential in addressing emerging energy conservation and sustainability themes.

Among the experimental projects presented, I recall the SERA (*Sistema Edilizio Residenziale Aperto*) Project, developed by the Production Cooperatives of Emilia-Romagna. The project aimed to prepare a catalog of "open-cycle" components designed through dimensional coordination and joint systems. These components were based on existing industrially manufactured elements adapted for the project by participating industries. This catalog marked the first (and only) attempt in Italy of which I am aware to experiment with an effective production system for "open-cycle" components. Even internationally, similar attempts were limited and largely unsuccessful. Unfortunately, the SERA Project did not progress beyond the production of an interesting catalog (a rare copy of which I still jealously preserve).

About a decade later, in 1994, I worked as a consultant on industrial research funding. I was called to assess a funding request of approximately 3 billion *lire* (approximately 1.5 million euros) from the same Cooperative Associations to implement the SERA Project industrially. Although I reviewed the project and visited the companies' facilities, I sensed that the enthusiasm and confidence once present in applied research had waned. It seemed as though the funding request was motivated more by financial concerns than by a genuine intent to pursue innovation in the sector. Around the same time, I was called to evaluate a funding request for 13 billion *lire* (approximately 6.5 million euros) submitted by Permasteelisa firm. The request was for applied research into advanced façade systems for office buildings, focusing on "double-skin" façades with high energy performance and systems for fully recovering energy produced by lighting and office equipment. The project involved renowned designers and consultants, including Renzo Piano and Thomas Herzog of the Munich Polytechnic.

It was clear that research on building innovation had already taken a different path!

In 1985, the National Council of Research CNR (*Consiglio Nazionale delle Ricerche*) established a commission to conduct a feasibility study for the Finalized Building Project (*Progetto Finalizzato Edilizia*) to advance the sector's scientific and technological development. Together with other notable figures such as professors Benedetto Colajanni, Giuseppe Ciribini, Marcello Grisotti, Pierluigi Spadolini, and Corrado Beguinot, I was invited to join the preparatory commission and later the executive committee of this five-year project, directed by Professor Paolo Bisogno (1989-1995).

The project included three thematic sections open to competitive proposals (*appel d'offres*) from researchers and industry players across Italy: technological innovation, typological innovation, processes and procedures. Many of the submitted and approved research projects were of considerable conceptual interest. Contrary to expectations, the most significant contributions to innovation did not come from advancements in construction technology or studies of production and implementation processes but rather from developments connected to ICT (Information and Communication Technology). Nowadays, it is evident that this outcome was inevitable.

One example is the research conducted by the CARTESIANA consortium (*Computer Aided Research Team for Expert System Implementation and Network Applications*). This consortium collaborated with the research group I led at the Department of Architecture and Urban Planning at the *Sapienza Università di Roma*. Together, we developed a knowledge-based model for representing building systems, known as KAAD (Knowledge Assistant for Architectural Design). This model later became a foundation and reference for subsequent and more recent studies on knowledge representation and collaborative design using techniques that would today be classified as Artificial Intelligence.

As we can see, the research trajectory inevitably diverged from the classical studies on building industrialization.

Despite the high expectations held by the scientific community and, to some extent, by industry stakeholders, the *Progetto Finalizzato Edilizia* had a limited impact on the actual construction world – if not an entirely negligible one. Numerous missteps contributed to this outcome. Chief among them was the insufficient involvement of the most innovative players in the industry and, concurrently, the failure to consider the digital revolution's effects on the sector adequately.

Construction was transforming through entirely different causes and pathways. Above all, the real innovation came from applying the digital revolution to construction materials and products, eliminating the need to mass-produce identical elements. This transformation was driven by the advent of computer-controlled machines, which allowed for parametric manufacturing and enabled the production of homologous components that were similar but not identical.

A paradigmatic example of this era was Frank Gehry's Guggenheim Museum in Bilbao, designed between 1992 and 1993 and inaugurated in 1997. The building's twisted, curvilinear forms, clad in limestone, glass, and titanium, were composed of unique and exclusive elements, each specifically designed for its precise location. As a matter of fact, in the early 1980s, pushed by the high-tech architecture movement, the construction industry began to customize building systems tailored to the innovative designs of new "starchitects", such as Norman Foster, Richard Rogers, Renzo Piano, Jean Nouvel, and Frank Gehry. Industries that embraced this architecture underwent a profound transformation, necessitating new construction technologies that shifted labor from traditional masons to precision-focused technicians akin to automotive workers. These industries developed innovative solutions, particularly in façade technologies, manufactured parametrically with computer-controlled processes.

Among the most prominent companies in this arena was the Italian firm Permasteelisa, founded by Massimo Colomban in San Vendemiano near Conegliano. Permasteelisa pioneered developing and producing cutting-edge components, becoming a key collaborator for leading architects worldwide.

At this juncture, Italy experienced an unforeseen phenomenon by academics and researchers: the industry began to translate the *haute couture* of architectural design, conceived by starchitects, into *prêt-à-porter* products for the construction market. However, this simplification process often banalized the quality of architectural expression, influencing contemporary architectural standards – frequently in a non-positive manner.

Today's typical construction site has become a complex mix of production activities where the industry provides highly diversified products that significantly diverge from the traditional notion of industrially prefabricated serial components. Instead, they generally combine on-site specialized artisanal craftsmanship for specific tasks, such as drywall partition systems and sophisticated industrial components customized to the specific project. The result is not the comprehensive industrialization of construction long pursued with firm belief by the great masters of the past – starting in the 1920s with Walter Gropius and Le Corbusier and continuing through Ciribini, Mandolesi, Spadolini, and others. Instead, what has emerged is a patchwork of solutions assembled on a case-by-case basis for each project and site. This hybrid approach blends artisanal and industrial methods, relying partly on standardized components and advanced but project-specific industrial solutions.

Thus concludes *The Great Illusion* – the illusion of a radical, all-encompassing industrialization of the construction sector. This illusion shaped the theories and aspirations of more than one generation of distinguished researchers. It now ends, alongside the prospects of closed-cycle building-model industrialization and open-cycle component industrialization. These approaches had been studied and heralded extensively but were deeply rooted in a dated cultural framework. This framework originated before the First World War, developed between the two world wars, and was based on the concept of mass-producing identical objects.

This outcome was inevitable. As our culture transitioned from industrial to post-industrial, how could we still expect construction to be a sector to fully industrialize – given the fact that it had never truly been industrialized in the first place? Today, construction is better characterized as a relatively underdeveloped sector with a growing tendency toward post-industrial forms of service-oriented production.

What remains relevant today from the half-century of research and experimentation? First and foremost, the history of those events and the enthusiasm of their protagonists. Second, and perhaps more fundamentally for Italian construction, the introduction of research itself into a world (even the academic one) that previously had no concept of what research meant. Finally, the sector incorporated essential principles of construction that are now indispensable: sustainability, energy efficiency, and performance-based standards. From the past studies, what endures is a rigorous methodological approach and techniques that may seem outdated but await rediscovery and application as reliable tools for project control – particularly when integrated with the latest computational simulation technologies.

Technology has always changed the world, from the invention of the wheel onward (perhaps even earlier). However, how these changes unfold depends on the cultural, social, and ethical attitudes of the society in which they occur.

The construction sector has been profoundly influenced by new technologies, primarily through the application of computers (with their countless uses) in design and production. This development has not only transformed the tools used but has also fundamentally altered how we think and perceive, becoming a vehicle for a new culture still in progress – a culture moving toward an uncertain future.

The power of computers has brought not only technical advancements to design but also the ability to construct and visualize unconventional geometric forms almost effortlessly. It has introduced a new way of conceiving architectural shapes, with both positive and negative consequences. The changing cultural context and pervasive globalization have done the rest.

Today, we face a crisis of values, a pervasive fear of the future, and a dominant sense of uncertainty. These are reflected in a design philosophy that breaks with the past, where increasingly complex technologies are called upon to address formal problems that cannot be understood or evaluated using the parameters of the recent past.

The unwavering faith of the "Great Masters" in specific ideological and cultural reference points has given way to relativism, where everything is virtually possible and justifiable.

In this relativist framework, there is no longer any place for *The Great Illusion*!

All figures are extracted from Pugnaletto M (ed) (2007) Operosità di Enrico Mandolesi. Centro Studi Consiglio Nazionale Ingegneri, Roma. See also Mandolesi's papers: https.//archivio.enricomandolesi.it