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Nursery school buildings in prefabrication techniques from the early 60s to the 80s in Italy. Historical, technological, and pedagogical overview

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Abstract

Prefabricated technologies have historically been associated with large-scale construction projects, particularly gaining momentum after World War II due to the demand for rapid and cost-effective building solutions. From the 1960s to the early 1980s, several innovative prefabricated systems were developed in Italy specifically for the construction of nursery schools. While prefabricated systems in compulsory school buildings have been extensively researched, innovative designs for nursery schools have largely been overlooked. The introduction of new cellular prefabricated systems has enabled a novel design approach, resulting in innovative school configurations that have significant implications for pedagogical practices. This paper provides a critical overview of the most widely used systems, transitioning from those based on the Camus model to those specifically designed to meet the needs of nursery school buildings. The novelty of this approach lies in the correlation between the new prefabrication systems and their associated pedagogical implications. It demonstrates how effective prefabricated technologies can address the educational requirements of increasingly flexible learning environments, accommodate potential spatial variations over time, and achieve a high level of environmental integration to optimize the efficient use of both indoor and outdoor spaces.

Keywords: Prefabrication, Nursery school building, Prefabricated system, Pedagogical needs

1. Introduction: prefabricated buildings in Italy

Industrialized construction is a widely accepted concept, but prefabrication is often mistakenly associated with it. Prefabrication is a combination of traditional and industrial methods used in construction, reducing costs by requiring less time, labor, and materials. It has been used in various forms, such as drywall systems, wall panels, floor panels, roof trusses, room-sized components, and entire buildings. Despite its benefits, prefabrication does not meet the criteria for industrialization. Prefabrication can be defined as the assembly of buildings or their components at a location other than the building sites [1]. As Olivieri observed in his book [2], prefabrication is a form of pre-existing industrialization. It can be traced back through the centuries.

Prefabrication, a technique rooted in ancient industrialization, offers numerous benefits, including time and cost savings, predictability due to controlled environments, increased safety due to workers operating in a protected environment, and a significant reduction in the influence of the construction site on surrounding activities. It eliminates external factors like weather and site accessibility, ensuring a safe and efficient construction process [3].

Economic considerations related to reducing costs, relocating some manufacturing activities, and reducing labor costs on site, have driven the Italian building industry toward prefabrication since the economic boom, particularly in response to the urgent need to recover the public residential building heritage [4]. Historical studies on housing reconstruction in the 1960s revealed that a higher proportion of a country's annual housing production provided by the public sector correlates with a more significant role of industrialized prefabrication methods within the broader construction industry [5]. Regrettably, there was a widespread belief that prefabrication was associated with *an interim* and unqualified product. Since then, prejudices have persisted and multiplied, evoking associations with lower-quality and less durable goods. Many designers perceived prefabrication as a tactic that limited and constrained their freedom of expression and creativity. On the other hand, adopting new construction techniques is considered a reliable strategy to help alleviate the housing crisis [6].

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Prefabrication, designed to reduce costs and delays, becomes unprofitable without large orders with a multi-year production horizon. Standardized systems can reduce construction expenses. Challenges arose in Italy due to the transformation of construction firms, affecting scale and time management [7]. Prefabrication faces psychological limitations due to traditionalist Italian building sector attitudes, leading to misconceptions about its true meaning and the need for significant scale and time management changes in construction firms [8]. Prefabrication was frequently mistaken for uniformity or disassembly [9] and believed to be detachable. Industrialized construction has been criticized for poor architectural quality and urban agglomeration all over Europe. Prefabricated systems were used to provide affordable, ready-to-use homes, but their effectiveness remains debated [10].

While the scientific literature has predominantly focused on the compositional, functional, and technological aspects of compulsory schooling buildings [11] constructed with prefabricated technologies, a significant gap in research regarding nursery schools is evident. The latter has not received the same level of attention as other prefabricated structures over the years [12]. Nursery schools have not undergone frequent seismic or energy adaptation and improvement interventions like different types of schools, leading to several persistent global deficiencies that continue to exist today.

The study critically examines the origin and development of prefabricated construction in nursery school buildings, highlighting limitations and constraints and providing a historical and pedagogical assessment of its benefits. Specifically, the work is divided as follows:

Toward this aim, the work is developed into the following parts:

i. A historical overview of the development of nursery school buildings using prefabricated systems;
ii. A critical assessment of the pedagogical advancements related to the prefabricated systems in assembling nursery school buildings;
iii. A technological appraisal of different patented prefabricated systems specifically designed for single-story schools.

1.1 The development of prefabricated nursery school buildings in Italy

In the 1950s and 60s, the post-World War II economic boom led to the rise of prefabrication techniques for shorter construction times. Initially used for industrial roofs, these methods faced limitations due to Italy's reliance on traditional methods and social and environmental barriers. Although building schools has always been a choice for municipalities and provinces, the government's decision to support prefabricated school buildings has led to the introduction of new regulations meant to stimulate research in this field.

Enzo Frateili [13] declared that "the school sector, alongside residential construction, has seen the most concentrated efforts to implement new construction processes in our country in recent years" ("*Il settore della scuola è quello dove, parallelamente con l'edilizia residenziale, più si è concentrato in questi ultimi anni, nel nostro Paese, il tentativo di attuare i nuovi processi costruttivi*").

The following decades were marked by an increasing demand for educational facilities brought on by population growth and the implementation of mandatory education. Quantitative concerns, including low enrollment, took priority over building quality issues, exacerbating pre-existing flaws and undermining the entire educational system. Attempts by the government to set up new schools with both conventional and innovative curricula have never been able to solve the shortages effectively.

To meet the needs of modern educational institutions, including those catering to the youngest students, Italian Law No. 444 was enacted on March 18, 1968, to establish nursery schools. Before that, private institutions provided service-related funding. However, with the advancement of women's role in Italian society, mass education became a pressing need. As more women enter the workforce, nursery schools are expected to support families and prepare children for elementary school. While the increase in school attendance, even among 3-6-year-olds, led to a notable rise in the demand for new buildings, advancements in technology also motivated builders to develop new types of buildings.

The Italian school construction industry experienced a slowdown during the late 1970s energy crisis, leading to changes in building design. Many schools abandoned natural light and ventilation for artificial lighting and mechanical ventilation, resulting in poorly designed classrooms and overlooked indoor comfort. In order to address this issue, prefabrication techniques were used to create compact buildings with load-bearing elements. The design of classroom layouts and functional areas in educational buildings was facilitated by applying functional flexibility, leading to the creation of shared spaces for multiple classes.

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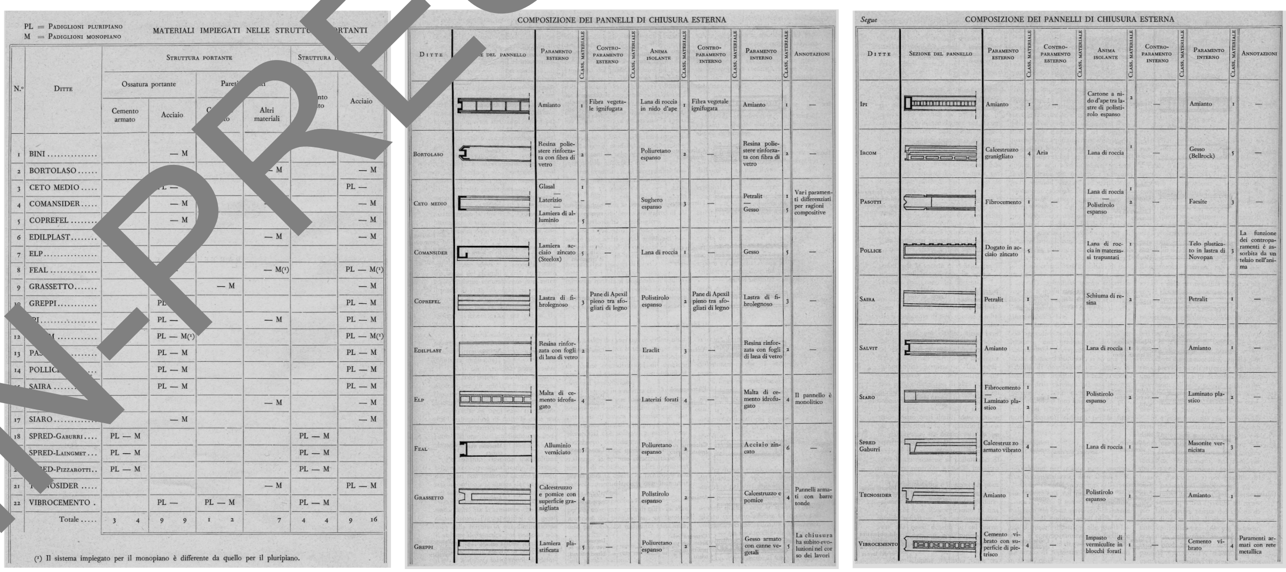
The Italian Law of 1962 [14] allocated 1400 million lire for prefabricated school buildings, marking the beginning of this sector and further disposition focused on classrooms and optimal functional and construction needs. Law 5 August 1975 [15] promoted national studies and experimentation in school prefabricated building types, promoting industrialized construction systems and flexibility, and guaranteed the full psycho-physical well-being of the occupants.

Figure 1: Two of the well-renewed Italian manuals for school building construction, front pages.



(a) (b) (c)

Figure 2: Materials chart (a) and external closing panels (b) (c) as described by the selected prefabrication companies after the 1962 competition. Source: Prefabrication in school buildings, Quaderni del Centro Studi per l'Edilizia Scolastica, n. 4-5, by the Italian Ministry of Education (1962).

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In accordance with the 1962 law, a national call for proposals was made to choose prefabrication companies. The agreement grants government control over contracts and their execution, with ISES (*Istituto per lo sviluppo dell'edilizia sociale*) delegated for the technical inspections. The Center for Studies of School Buildings supervised operations and published several valuable manuals to support designers (Fig.1). The contract competition involved selecting prefabrication companies and constructing the system using modular pieces. Of the 108 invited companies, 43 submitted applications, and 24 met the eligibility standards. By the end of 1965, 339 school buildings were built, featuring an overall capacity of 2767 classrooms.

The prefabricated solutions (Fig. 2) from the 21 selected companies demonstrated a lack of creativity, as their products frequently replicated conventional wall structures. The standard responses to modular systems and panels neglected fundamental principles of internal composition, leading to missed opportunities for benefits such as cost reduction.

Modularity systems and panels were replied to in a very standard way, with scarce attention to the internal composition principles that can positively affect the educational models. Due to these limitations, the expected benefits of prefabrication, which included a decrease in the expenses and time associated with cost, production and utilization, were widely overlooked. Following the introduction of Italian regulations that encouraged innovation in prefabricated school buildings, several prefabricated systems were developed for schools afterwards.

1.2 Plan flexibility opportunities in prefabricated nursery schools

The plan flexibility that the prefabricated systems offered in comparison to the traditional techniques (solid brick walls and concrete beams) allowed the designers to experiment with new plan dispositions. New spatial aggregation mechanisms, which are special to nursery schools, were used for both external walls and interior partitions. These mechanisms can be summed up in two main schemes (Fig. 3), based on parallelepiped-shaped cells that are assembled using prefabricated building components:

1. Planimetric proliferation of cells (dimensionally identical);
2. Organic planimetric expansion of homogeneous cells.

Three open and flexible aggregations arise from the two methods mentioned above [16]. With the benefits of mass production, a variety of architectural and spatial mechanisms can be developed from these three plans to best respond to varied pedagogical and environmental contexts.

a. Comb scheme (*schema a pettine*);
b. Z scheme (*schema a Z*);
c. Cluster scheme (*schema a grappolo*).

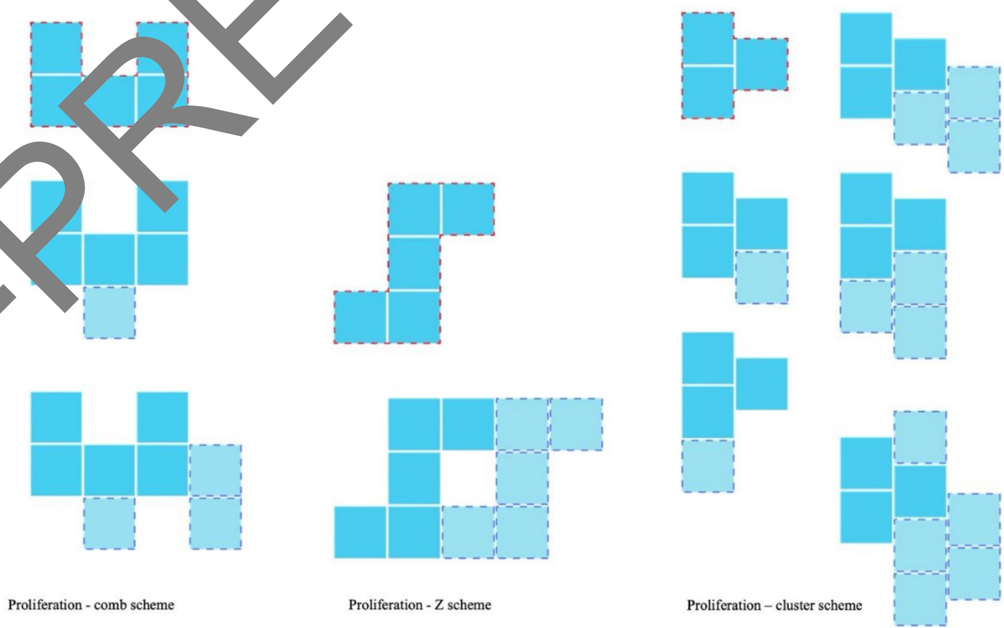

Figure 3: Proliferation schemes, according to three different mechanisms (elaboration by the authors).

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The comb scheme is a spatial organization based on repeating cells, alternating repetitions and flanking rectangles. Glass walls provide access to open spaces, with each unit having three open sides. Thus, each branch accommodates one nursery school section, which can be expanded and transitioned to multiple sections through proliferation. The Z scheme is a structural unit system consisting of five elements, with three linearly arranged and two at the top and bottom left, regulating the shared environment and allowing for expansion and doubled layouts (Fig. 3). The cluster scheme is a flexible scalar aggregative model consisting of three structural units, allowing for various internal and external organization and volume growth. It features a planar arrangement of two units and a staggered third unit.

1.3 Spatial consequences and pedagogical aspects

The pedagogical unit (*sezione*) is a new mixed space designed for educational and holistic purposes, replacing the traditional classroom. It consists of interconnected spaces and subspaces that facilitate various teaching experiences, from routine tasks like lunch and personal hygiene to quieter activities like desk work and active pursuits like indoor and outdoor play. This concept replaces the traditional classroom with a more complex and varied area.

This setup allows for both whole-group and small-group activities, catering to the diverse needs of all the children in the section. According to the description of a school project [17] from the late 1970s in Carpi (Modena): "The articulated design of the classrooms, along with the inclusion of openings specifically tailored for children, ensures complete autonomy for each section concerning lunch, changing rooms, cleaning, and bathrooms. Additionally, the provision of porticoes and play areas in front of each classroom, as well as easily accessible outdoor spaces adjacent to the common room, enhances the overall environment. Finally, the visual and functional continuity between all these internal and external spaces is rooted in the belief that the environment as a whole can stimulate a child's interest in the various activities that take place there, mainly when there is a seamless transition between different moments of child engagement. This approach serves as a crucial foundation for the harmonious development of the child's personality".

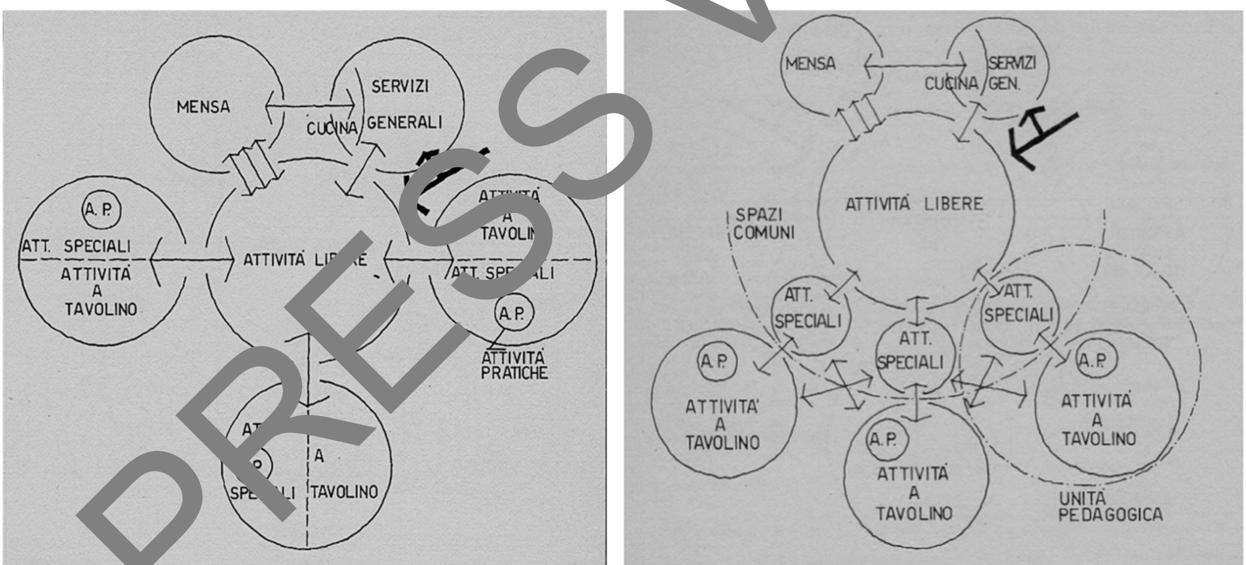

Figure 4: Nursery school distribution plan based on ministerial requirements (left) and internal distribution of nursery schools according to the new approach. Source: Italian Ministry of Public Education (eds.) La prefabbricazione dell'edilzia scolastica, quaderni del centro studi per l'ediliza scolastica, n.4 e 5, 1965.

The section is not intended to be a separate entity from the rest of the school [18]. Therefore, it should not act as a barrier to more specialized activities that cater to small groups of children from different sections. During that time, a method was investigated to enhance interaction among children from different groups, as opposed to the traditional approach, where such interaction only took place during lunchtime [19].

The traditional solution was challenged by the "open solution" [20], which achieved a high degree of flexibility by replacing all the internal walls with movable walls made of wood or plastic materials. On a pedagogical level, however, this technique encountered considerable pushback since the youngster felt lost and puzzled at not being able to locate something stable. It was determined that being too free-form is equally deleterious as being forced into strictly

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predetermined places, times, and activities.

Therefore, sections were created by dividing the spaces into closed, open, and intermediate areas shared by several sections. Areas were designed to accommodate flexible and spontaneous activity [16]. Spaces were integrated visually and functionally to facilitate a gradual transition from activities designed for small groups to those intended for larger groups and from section-based activities to mobile group activities across different sections.

The adoption of a prefabricated system could allow for a new vision of the nursery school [17]: "In our view, the school should be conceived as an association comprising no more than three sections organized around a central hub—a heart—effectively serving as the focal point of the entire school's community. This structure fosters operational interrelationships and enhances spatial connections among all educational areas".

The *atelier*, a space for group activities, underwent significant improvements to cater to various events and activities. Its dimensions, lighting, layout, and outdoor connection were carefully considered to support storytelling, impromptu performances, group creative work, and collaborative work.

2. Prefabricated systems reviews for nursery school buildings in Italy

The French CAMUS system [21] was a sophisticated prefabricated system made of load-bearing reinforced concrete panels and one of the most diffuse systems in Europe. It was considered a pioneer in prefabrication for residential buildings and was then implemented in construction schools with some modifications, mainly adjusting the facade panels' openings and dimensions to meet non-residential needs.

The load-bearing internal transversal panels and exterior facade panels are crucial components of the building's structural system. The external walls are made of reinforced concrete panels with a load-bearing function and a thickness of 24 cm. Each panel consists of an outer layer of reinforced concrete, a layer of expanded polystyrene for insulation, and an inner layer of reinforced concrete with a welded metal mesh interlayer. External coverings can be added to the final layer of the panels. The flooring consists of 14 cm-thick concrete slabs with upper and lower-face electro-welded meshes.

In 1961, heavy prefabrication debuted in Italy, primarily applied to public housing and other large building complexes. This development was inspired by the increasing popularity of French prefabrication systems, particularly the well-known patents of Balency, Barets, CAMUS, and Coignet. Building on those experiences, several Italian patents were subsequently developed, including:

Besides the well-known CAMUS system, five additional prefabrication systems (Fig. 5) that resembled the French ones were developed in Italy during that period [22]:

- *Girola* system, designed by Eng. Paolo Vi[illegible]a; owner company: Umberto Girola S.p.A., Milan;
- *Borini* system, design and company owner Eng. Franco Borini, figli & C., Turin;
- *Codelfa* s.p.a. system, design by Eng. Aldo Spirito & Franco Scarantino; owner company: Codelfa S.p.A. costruzione Del Favero, Milan.
- *Gerola - Co-Ge-Far* system, designed by Arch. Luciano Gerola; owner company: Co-Ge-Far, Milan;
- *Sacie-Koncz* system, designed by Eng. Tihamer Koncz; owner company: Sacie S.p.A., Milan.

Among the most profitable companies in prefabricated construction, Umberto Girola developed a patented structure with a steel profile framework, self-supporting brick floors, and concrete panels. These elements rest on the extrados of beams with an average thickness of 12 cm. The sandwich panels are composed of two layers of reinforced concrete (5.5 cm each) and a layer of expanded polystyrene (2.5 cm), resulting in a total thickness of 13.5 cm. Additionally, the partitions are made of honeycomb plaster panels and false ceilings with sound-absorbing plaster panels. The roofs are constructed from corrugated sheet metal and are insulated for both thermal and acoustic performance. The connections are made of a push connection system (Fig. 5).

Most of the school's prefabricated systems were constructed using flat load-bearing panels with a transverse structural system. Exceptions include the Borini and Codelfa systems, which incorporated both transverse and longitudinal structural systems. In most cases, the joining mechanisms rely on pins or joints, leading to significant variability in the width of thermal bridges. As illustrated in Figure 5, most of these systems were designed for factory production, except Borini's patent, which permitted staged production, and the Gerola [23] and Codelfa systems, which allowed for modifiable production methods.

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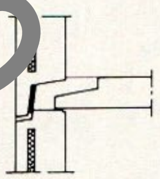
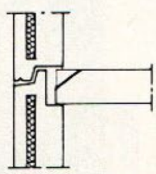
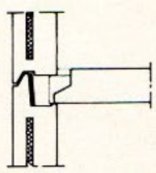
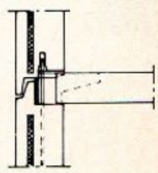
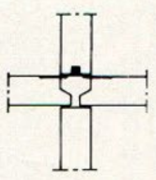
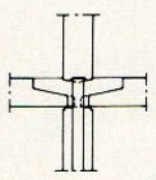
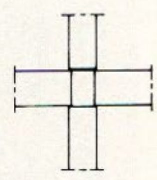
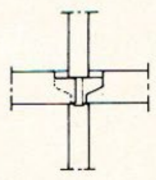
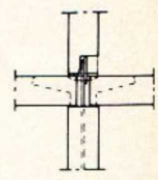
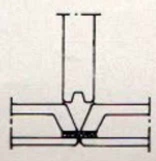
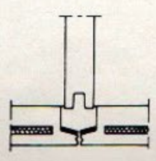
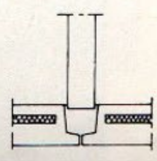
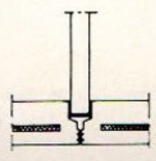
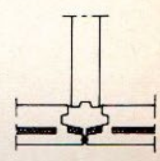
CARATTERISTICHE	SISTEMI				
	SACIE-KONCZ	GIROLA	BORINI	GEROLA	CODELFA
ELEMENTI	Pannelli portanti piani	Pannelli portanti piani	Pannelli portanti piani	Pannelli portanti piani	Pannelli portanti piani
SCHEMA STATICO	Trasversale	Trasversale	Trasv.-Longitud. incrociato	Trasversale	Trasv.-Long[illegible] incrociato
COLLEGAMENTO GIUNTI ORIZZONTALI	Saldatura e getto	Getto	Saldatura e getto	Saldatura e getto	G[illegible]o
COLLEGAMENTO GIUNTI VERTICALI	Getto	Getto	Saldatura e getto	A secco	[illegible]tto
GIUNZIONI PANNELLI COMPLANARI	Concentrate ai piani	Distribuite	Concentrate	Concentrate ai piani	Conc[illegible] ai [illegible]iani
CENTRAGGIO DEI PANNELLI	Piastre con spinotti	Spinotti		Incas[illegible]i	Ga[illegible] di imbrago
Nº OPERAZIONI GETTO E SIGILLATURA PER PIANO	3	2	3	1	2
SEZIONE DI GETTO NEL GIUNTO ORIZ. ESTERNO	120 cm²	255 cm²	135 cm²	[illegible]	270 cm²
SEZIONE DI GETTO NEL GIUNTO ORIZ. INTERNO	125 cm²	403 cm²	[illegible]6 cm²	279 cm²	445 cm²
SEZIONE DI GETTO NEL GIUNTO VERT. ESTERNO	130 cm²	220 cm²	[illegible]	—	235 cm²
AMPIEZZA MASSIMA DEI PONTI TERMICI	—	7 cm	18 cm	6 cm	5 cm
IMPERMEABILIZZAZIONE GIUNTO VERTICALE	Impermeabilizzato	Posteriormente ventilato	[illegible]eabilizzato	Posteriormente ventilato	Posteriormente ventilato
IMPERMEABILIZZAZIONE GIUNTO ORIZZONTALE	Impermeabilizzato	[illegible]permeabiliz. + sagoma a gradino	Impermeabiliz. + sagoma a gradino	Impermeabiliz. + sagoma a gradino	Impermeabiliz. + sagoma a gradino
PRODUZIONE	In stabilimento	[illegible]stabilimen[illegible]	In stabilimento o a piè d'opera	Impianto mobile	Impianto mobile
GIUNTO ORIZZONTALE ESTERNO					
GIUNTO OR[illegible]ALE INTERNO					
GIUNTO VERTICALE ESTERNO					

Figure 5: Comparative overview of the five prefabricated Italian systems derived from the CAMUS French system. Source: Oliveri G M, Prefabbricazione o metaprogetto edilizio, Etas compass, Milan, 1968.

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Borini system offers exceptional flexibility and versatility for both small and large-scale construction projects. This prefabricated system consists of load-bearing panels assembled on-site to create a box-like structure. The primary components include sandwich facades, which feature a load-bearing concrete layer (14.5 cm thick), a layer of polystyrene, and an external protective layer made of cement conglomerate (5 cm thick). These layers are reinforced with electro-welded mesh and are interconnected by galvanized iron elements that pass through all three layers. Additionally, the system includes load-bearing walls made of solid concrete conglomerate, as well as non-load-bearing walls and floors constructed from reinforced concrete.

Gerola system relies on the use of three-dimensional elements, which are achieved by assembling three-dimensional boxes or half-boxes. These components can be coupled in three directions, enabling the creation of various buildings with one or more floors. The primary element consists of three walls and two floors, constructed from monolithic cast concrete with an insulating layer of extruded polystyrene. These elements are fully manufactured in the factory. The Gerola system can utilize both joints and welding plates, which are employed to seal the various cells directly on-site.

Sacie S.p.A. patented the Sacie-Koncz panels, which are constructed from solid concrete and incorporate a layer that serves as thermal insulation. The load-bearing structure, also prefabricated, is already connected to the foundations on site. This system enables the development of a wide variety of combinations that can be completed in a short timeframe.

In Europe, many other systems were developed, such as the CLASP (Consortium of Local Authorities Special Programme) system [24], which was developed in England in 1957 to create a prefabricated school building program to be applied all over the country, as well its following patented systems, known as *SCOLA* and *MACE* [25].

In Italy, the CLASP system was awarded by the Milan Triennale as the most outstanding school building system in 1960. Its use in Italy and other nations followed this success. This system has been gradually gaining momentum. Nonetheless, other national prefabricated and local and regional systems in Italy have found a more widespread diffusion [26].

Given the widespread adoption of various prefabricated systems in Italy and abroad, there has been a growing focus on specially patented prefabricated systems designed to meet the specific needs of educational buildings. The following paragraphs will provide an overview of the most prevalent Italian systems developed for constructing new school facilities.

2.1 The Stager System

The engineers Nicola Germano and Massimo Starita invented the prefabrication system with modular pieces called Stager. Then, Vibrocement S.p.a. in Perugia acquired the patent. Stager is a reinforced concrete prefabrication method for coordinating components. It operates on a 10 cm scale and creates modular spaces in both directions, ranging from 9 to 34 vertical modules and 15 or 30 horizontal modules. There are four main parts: flooring, beams, panels, and pillars. The horizontal structure on the ground floor consists of elements that are prefabricated from brick and concrete, with finishing casting performed on-site. In contrast, the horizontal structure on the roof is partially composed of ribbed plates that rest on the perimeter beams.

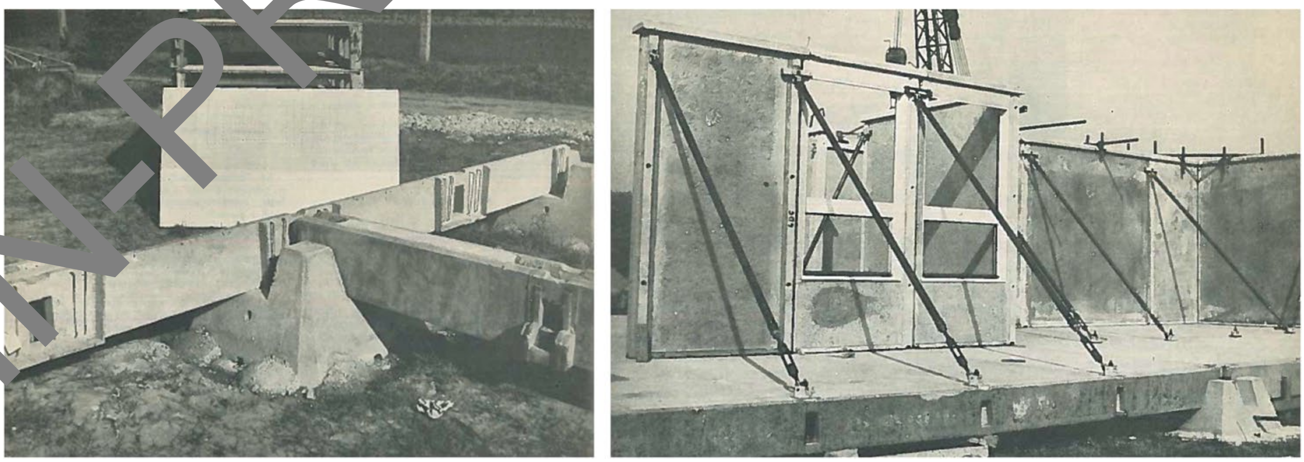

Figure 6: View of the construction site with the insertion of beams (on the left) and vertical panes. Source: Forlipedia, www.forlipedia.it".

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The Stager system offers quick installation and flexibility in nursery school interiors, with three main areas: the section area, the common area, and additional areas like bathrooms and changing rooms. This innovative principle maximizes individual developmental stages by dividing the classroom into sections for similar children and a common room for social interaction [27]. The common room serves as a hub for social interaction and knowledge sharing, connecting with sections, the kitchen, and the entrance. Prefabricated panels enable plan design and ongoing interaction.

2.2 The Standard Scuole System

The Consortium of Production Cooperatives and Work of the Province of Forlì developed the *Standard Scuole* prefabrication construction system, using reinforced concrete and expanded clay conglomerate panels. The system features a static structure with load-bearing frames, external infill panels, and floors that can span long distances.

The floors can span great distances without the need for precompression: up to 9.50 m and up to 8.40 m on beams that are part of the floor's thickness. A grid with a mesh size of 120 x 120 cm enabled modular coordination among different parts of the building, allowing for several internal configurations in school buildings.

Figure 7: Historical pictures of the Standard Scuole system on construction sites. Source: Forlipedia, www.forlipedia.it".

The system uses two load-bearing structures: a prefabricated reinforced concrete frame with ground-level plinths and stiffening beams and an external perimeter structure with panels. The horizontal slabs create ventilated spaces underneath each flooring structure. The panels of expanded clay, approximately 22 cm thick, form the opaque external enclosures.

The internal flat-section partitions comprise prefabricated, 50 x 70 cm identically sized blocks of silicalcite with a plaster outer surface. The flexibility provided by the width of the *Standard Scuole* system panels for horizontal and vertical closures makes the prefabricated system highly suitable for larger nursery schools, offering extensive possibilities for aggregation following the initial aggregation cells.

2.3 The S3 System

The so-called *S3* system was designed by the *Consorzio Provinciale delle Cooperative di Produzione Lavoro e Trasporti di Bologna* (C.P.C.P.L.T.). The *S3* system was designed for constructing school buildings [28]. Due to its high degree of adaptability, it could be tailored to the specific requirements of each municipality, making it suitable for a variety of projects. The system could be customized to meet diverse needs.

The S3 system is a prefabricated, pre-stressed system for classrooms, utilizing linear reinforced concrete parts with a maximum weight limit of 4000 kg. The modular grid controls component sizes based on classroom layout dimensions and light requirements.

The system features pillars with a constant cross-section, double T-beams, and flooring made of longitudinal and transverse rib plates (Fig. 8). The initial beam solution was abandoned due to the high costs associated with overstocking. The construction process involved five structures: a pillar, a beam, two attic elements, and stairs. The system aims to provide a more efficient and light-efficient classroom environment.

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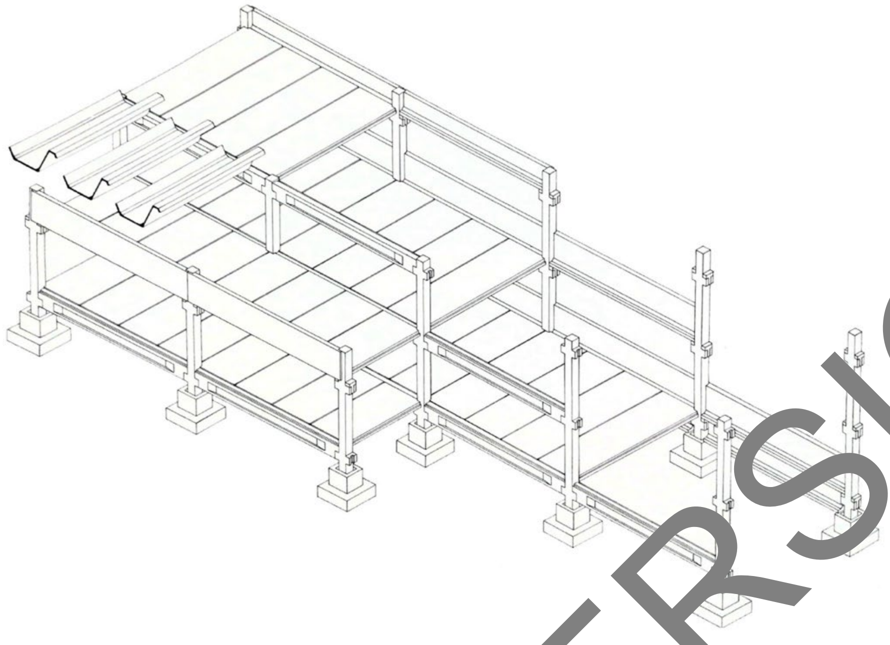

Figure 8: Axonometric scheme of the 3S System (1977).Source: Consorzio Provinciale delle Cooperative di Produzione Lavoro e Trasporti di Bologna.

2.4 The CMB System

The *Cooperativa Braccianti* of Carpi, established on November 27, 1904, and the Bricklayers Cooperative Society, representing Carpi's cement workers and carpenters, merged to form the CMB. This company is still acknowledged today as one of the largest in the prefabrication industry in Italy. In 1977, their union gave rise to the CMB of Carpi (Modena).

A prefabricated brick-cement framework and finishing system for residential and educational buildings was patented in 1966 by the CMB in Carpi [29].

The core of the CMB prefabrication system included load-bearing panels that were not fully prefabricated, along with a variety of small and medium-sized element dimensions. The joints, completion of the structure, foundations, and some roof elements were assembled on site. The construction consisted of panels for the external and roofing walls; traditional materials were mainly used to create the vertical elements, while prefabricated horizontal structures were also incorporated [30]. Because prefabricated components were assembled independently, they were suitable for structures of any size, whether single or multiple stories. These features have led to the widespread adoption of the CMB system in the Emilia Romagna region for new nursery and school buildings.

One of the most interesting innovations that distinguishes the CMB patent is the construction procedure that enables the production of elements with a modest weight, less than 3 kg/m^2.

The open-loop process allows for versatile design and typological choices, with a wide range of assemblies and production equipment features, enabling customization of internal and external finishing materials.

The CBM system was patented in 1966. The authors discovered all the technical details in the private archive of the *Cooperativa Muratori, Cementisti e Carpentieri di Carpi* (CMB) in the manual entitled *Prefabricated structural and finishing brick-cement construction elements for school and residential buildings* (*Elementi costruttivi latero-cementizi prefabbricati di struttura e di finitura per edilizia scolastica e abitativa)*. (Fig. 9)

The prefabricated exterior panels are installed at intervals of two meters and have a thickness of 32 cm. Each panel consists of a central mixed section placed within a perimeter frame made of T-armed concrete. The panels are used to construct exterior walls. They are joined to one another by an on-site cast joint.

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Figure 9: External view of Gianni Rodari primary school in Carpi and the central common room with lowered ceiling beams. Source: https://www.cmbcarpi.com/storia

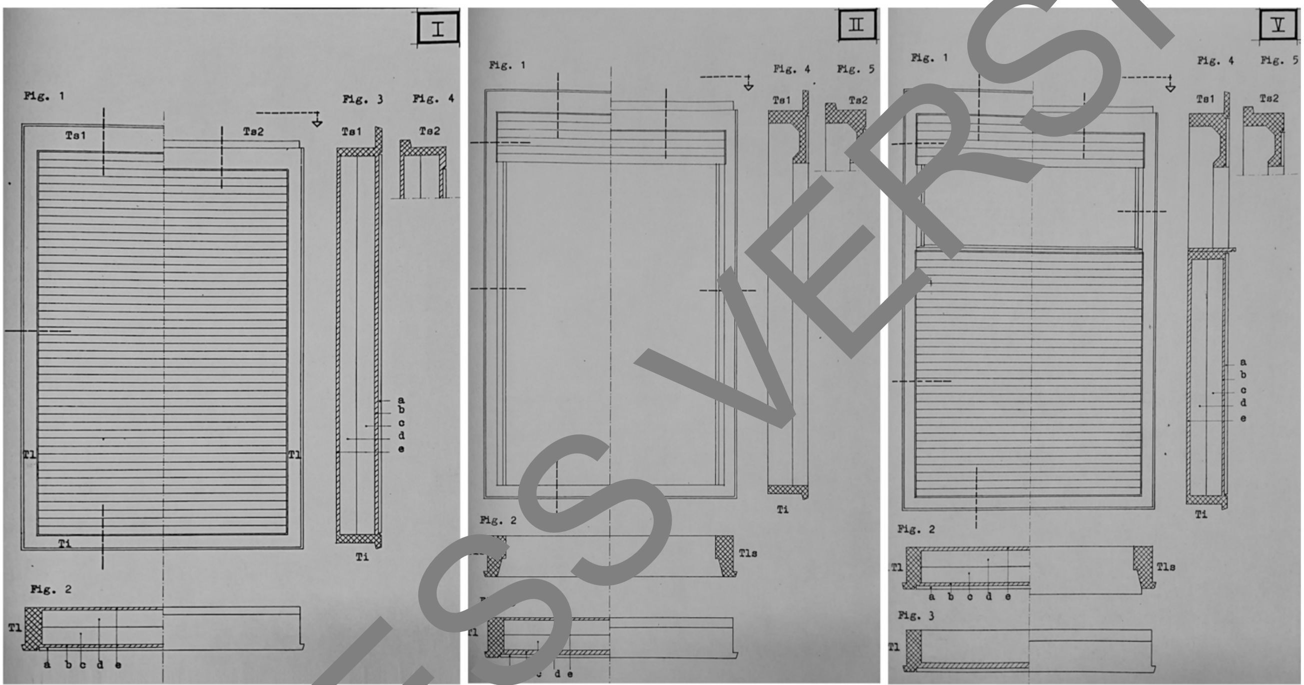

Figure 2: Standard CBM panel types: (a)blind panel;(b) with external door;(c) with small window opening. Source: CBM historical archives.

The panel's outer frame is made of reinforced concrete, which supports its weight. The frame's exterior edges feature specific designs that facilitate installation, enable connections to other prefabricated components, and allow for the placement of casting to complete the load-bearing structure. The standard panel has the following structure (Fig.10):

a) external cladding made of coloured marble chips that have been scraped and cleaned -1.5 cm;
b) fine-grained, thin concrete slab reinforced with thick metallic – 5 cm;
c) a layer of perforated brick elements - 12 cm;
d) a layer of perforated brick elements with staggered joint – 15 cm
e) plaster interior finishing with thick cement and bastard mortar lime – 1cm.

The standard panel can differ in layer (d), which can also be realized in concrete and expanded clay conglomerates.

2.5 *Limitations, potentials and performance of modular prefabricated nursery buildings*

Modular prefabricated construction serves as the foundation for new school buildings in Italy. The construction elements have been developed using various patented systems, each featuring slight variations in their structural frames, construction components, and panel joint methods.

The potential inherent in cellular and prefabricated models effectively addresses the educational needs of nursery schools. The new distribution model significantly benefits from the flexible management of spaces and the modular

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reusability of sections and other secondary areas. The compositional freedom offered by various systems has supported the construction of schools of different sizes for decades, allowing for increasingly complex spatial aggregations that promote more flexible and adaptable management of both indoor and outdoor spaces to accommodate classes of varying ages. Today, despite the well-recognized advantages of prefabricated school systems, many of these buildings are undergoing significant retrofitting to comply with recent seismic regulations, energy efficiency standards, and environmental requirements. Acknowledging the most prevalent deficiencies, which primarily relate to their overall energy performance, the greater potential of these prefabricated panels and other slabs lies in their stratigraphic and modular features. Currently, various commissioning actions can be easily implemented by removing and replacing existing air conditioning ducts and electrical systems, upgrading lighting fixtures, or adding thermal or soundproof insulation within the already installed false walls or ceilings. Ultimately, these actions do not require alterations to the modularity and repetitiveness of the originally defined system dimensions or the initial composition schemes.

3. Conclusions

After World War II, Italian companies shifted their perspective on prefabrication, adopting new technical standards for new school buildings. The new standards, adopted in December 1975, led to the creation of a single-building organism facilitated by standardized prefabricated panels. This allowed for flexibility and changeability over time for internal spaces and allowed for school grouping complexes with shared services and equipment. The new systems also recognized the importance of technological aspects in plant engineering systems. The classroom unit was recognized as complementary to the overall teaching space but still considered an essential element.

Understanding each system's patents and historical evolution is crucial for designing, retrofitting, and enhancing existing schools today. As demonstrated by the historical overview, while commonly shared among most patents for prefabricated panels, the construction methods shared unique features and distinctive elements that must be carefully considered to implement optimized energy and environmental requalification interventions. The typological and technological analyses of the primary types of technological elements used in modern prefabricated kindergartens should serve in developing interventions aimed at improving energy efficiency, seismic resilience, and environmental rehabilitation tailored to various school buildings.

Furthermore, capitalizing on the repetitive nature of modular elements and recognizing the replicable characteristics of specific components that constitute the building envelope and structure can be an effective strategy for managing the costs of a retrofit project while minimizing future maintenance expenses. Further considerations should address seismic and energy issues, as these topics, which were previously secondary during the construction phase, are now of primary importance in the context of retrofit strategies. This focus is essential to ensure a more sustainable environment that meets educational needs.

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5. Author Contribution

Barbara Gherri is responsible for conceptualization, formal analysis, methodology, and writing; Federica Morselli is responsible for data curation and resources.

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