

## Precast concrete school buildings the future in Spain

Oriol Pons

Since the beginning of the 21st century, more than 200 public schools in Spain have been built using industrialized methods of construction. Half of them have employed renewed prefabricated concrete technologies. Fifty years ago, similar methods were used to build thousands of buildings all over Europe. Although such technologies offered high construction speed at low cost, they resulted in mass-produced identical structures of low quality.<sup>1</sup>

Schools built in the present century have been erected quickly as well, but each structure has been adapted to its urban context and community necessities. These new schools are modern educational centers that meet the latest standards for quality, comfort, and sustainability. Moreover, these new schools serve as examples of well-designed architecture.<sup>2</sup>

### Context

In the 1960s, the first Spanish prefabricated school buildings were constructed employing the same industri-

alized techniques used for housing structures.<sup>3</sup> Still, most schools were traditionally built. In the 1970s, many more schools were built using prefabricated techniques. Spain needed to make room for students in urban settings as families migrated from rural areas. Therefore, the government invited companies to bid to construct mass-produced school buildings.<sup>4</sup> Hundreds were prefabricated according to Finnish and North American patents.<sup>5-6</sup> These structures were built in an average time of eight months and at an average cost (in today's dollar value) of \$700/m<sup>2</sup> (\$65/ft<sup>2</sup>).<sup>7</sup>

In the 1980s and 1990s, few school buildings were prefabricated. Since the beginning of the 21st century, more than 200 schools, mostly kindergarten and primary, have been built using industrialized methods in Spain.<sup>8</sup> The previous decade saw an expanding economy and a demographic redistribution: thousands of immigrants arrived in the country while many families moved from the centers to the outskirts of cities. New schools became necessary in different parts of the country. The government's solution was to build permanent prefabricated schools. In order to gain social support for this policy, these newly built schools would meet the highest quality standards and have an appearance similar to nonprefabricated ones. In 2002 the first of these school buildings



Escola Gerbert d'Orlhac in Sant Cugat, Spain, was built in 2003. It was designed by Pich-Aguilera Architects. In eight months, the school was designed, produced, and executed. Courtesy of Jordi Bernadó.



Escola Les Arenes in Terrassa, Spain, was built in 2005. It was designed by the architect A. Ubach. *Courtesy of Oriol Pons.*

was prefabricated. The government's policy has evolved as follows:

- From 2002 to 2004, more than 40 schools were prefabricated in limited time frames. In six to eight months, the school was designed, produced, and executed. When a school was needed, designers were invited to bid to design it using prefabricated technology. Then, construction companies bid to construct the school according to the winning design.
- From 2005 to 2007, more than 60 schools were prefabricated in longer time frames (14 to 16 months) in order to achieve improved results. The contractual process also changed to the design-build concept. When a school was needed, construction companies were invited to bid on a design-build contract to design and construct schools. These construction companies were responsible for the entire project from design through construction.
- From 2008 to 2010, more than 60 schools were prefabricated in similar time frames with similar contractual processes as from 2005 to 2007.

In summary, many prefabricated schools have been built successfully in the new century and have solved

existing needs. More than 100 of the schools have been prefabricated with precast concrete technologies. At the present, no school buildings are needed and the Spanish government's budget has decreased because of the economy. Soon, the number of prefabricated schools built per year will decrease abruptly. However, there may be a need for new kinds of precast concrete school buildings, such as flexible and mobile schools. These mobile schools could serve as a primary school in one town for three years and then move to another town to serve as a high school for two years.

### **Main precast concrete technologies used from 2000 onward**

Prefabricated school buildings have been built using the following three systems:

- precast concrete frames, hollow-core slabs, and facade panels
- precast concrete room modules, hollow-core slabs, and facade panels
- precast concrete structural walls and slabs

These three methods of construction have some common characteristics. The structural components and the solid part of the facades are prefabricated, but not the other parts of the buildings. The structural and facade



Escola Frutuós Gelabert in Barcelona, Spain, was built in 2008. It was designed by Basterrechea/Tejada Architects. *Courtesy of Oriol Pons.*

components are produced in similar precast concrete factories, though different molds are used to cast each piece.

All three concrete technologies have many advantages compared with those prefabricated with other materials. They have better fire resistance, so it is not necessary to protect structural elements with special noncombustible materials. Their massive structures and facades have a useful thermal mass to keep the interior at the desired temperature with less energy consumption. They are also better at insulating against exterior noise.<sup>9</sup>

More than 100 public schools, mainly kindergarten and primary, were built using these methods. They have a similar functional layout that includes a kindergarten area, an elementary area, a community-use area, and a gymnasium. However, each school's shape is customized to meet community and urban requirements.<sup>10</sup> This paper studies three representative schools, located in Barcelona, Spain, and nearby towns.

### **Precast concrete frames, hollow-core slabs, and facade panels**

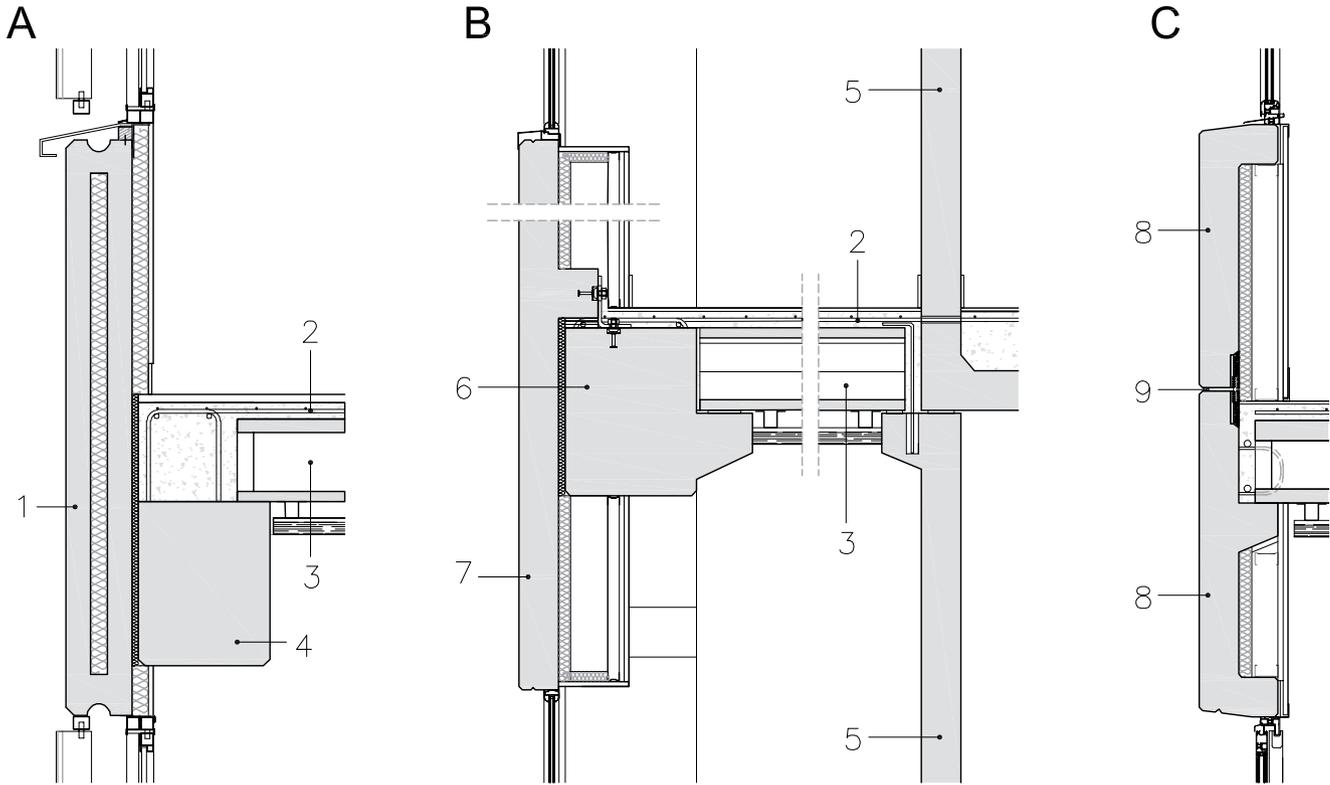
Technology using precast concrete frames, hollow-core slabs, and facade panels is a renewal of previous systems used in the 1960s and 1970s in Europe and North America. Since 1980, many Spanish precast concrete companies have been using this technology for industrial buildings. In the 1990s, these firms started prefabricating other building types: commercial structures, offices, condominiums, and schools. Since 2002, as many as 100 schools have been assembled using this method.

This system's structure is composed of precast concrete frames and hollow-core slabs. Frames have continu-

ous columns with orthogonal cross sections that vary from 40 cm × 40 cm (16 in. × 16 in.) to 60 cm × 60 cm (24 in. × 24 in.). Beams can be reinforced or prestressed with a variety of shapes and widths. Hollow-core slabs are prestressed, 16 cm to 40 cm thick (6 in. to 16 in.), and span up to 12 m (39 ft). During assembly on-site, these slabs are completed with a layer of concrete topping. Joints between structural elements are also filled with reinforced concrete.

This method's facade also has non-load-bearing precast concrete panels that are 10 cm to 20 cm thick (4 in. to 8 in.) with either a solid section or a sandwich section. Panels lie on columns or beams using special bolted connections.<sup>11-12</sup> Interpanel groove-and-tongue joints are sealed from the outside using silicone.

Escola Juncadella was built in 2009 using this system. It was designed by the architect J. M. Fort. Its shape complements its urban context and creates different spaces for each educational area. It measures 3168 m<sup>2</sup> (34,100 ft<sup>2</sup>) and cost \$6.3 million (in today's dollar value), or \$1989/m<sup>2</sup> (\$185/ft<sup>2</sup>).<sup>7</sup> Its structure has frames composed of multilevel columns with a 40 m × 40 m (16 in. × 16 in.) cross section and beams with a 40 m × 50 m (16 in. × 20 in.) cross section. The hollow-core prestressed concrete slabs have a 120 cm × 25 cm (47 in. × 10 in.) cross section and span 7 m to 9 m (23 ft to 30 ft). The building's facade is composed of 20-cm-thick (8 in.) sandwich panels with a maximum surface area of 2.5 m × 11.1 m (8 ft × 36 ft). Facades have painted smooth panels.



Details of the studied schools: A. Escola Can Juncadella, B. Escola Àngels Alemany, C. Escola Vinya del Sastret; based on their design drawings. Legend: 1) 20-cm-thick (8 in.) sandwich precast concrete panel; 2) 5-cm-thick (2 in.) cast-in-place concrete topping layer; 3) 25-cm-thick (10 in.) hollow-core slab; 4) Precast concrete beam with a 40 cm x 50 cm (16 in. x 20 in.) cross section; 5) 12-cm-thick (5 in.) load-bearing room module; 6) Precast concrete beam with a 40 cm x 50 cm (16 in. x 20 in.) L-shaped cross section; 7) 12-cm-thick (8 in.) massive precast concrete panel; 8) 12-cm-thick (5 in.) load-bearing wall; 9) Joint between panels with welded steel pieces and filled with mortar.

### Precast concrete room modules, hollow-core slabs, and facade panels

In Spain, precast concrete room modules, hollow-core slabs, and facade panels have been used to build 18,000 m<sup>2</sup> (194,000 ft<sup>2</sup>) of school buildings from 2003 to 2006. The method's structure uses precast concrete room modules and hollow-core slabs. Modules have U-shaped horizontal and vertical sections and can measure up to 2.4 m x 3.3 m x 6 m (8 ft x 11 ft x 20 ft). Their three walls and floor are 12-cm-thick (5 in.) reinforced concrete. Hollow-core slabs are prestressed slabs 16 cm to 40 cm thick (6 in. to 16 in.). They span up to 12 m (39 ft). The assembly on-site is conducted level by level. Lower modules support hollow-core slabs, perimeter beams, and the upper-level modules. Joints between precast concrete components are finished on-site with reinforcement bars and concrete, along with a layer of topping concrete.

This technology's facade is composed of non-load-bearing precast concrete panels that are 10 cm to 20 cm thick (4 in. to 8 in.) with either a solid section or a sandwich section with expanded polystyrene boards inside. The panels are connected to the perimeter beams with

bolted steel angles. Tongue-and-groove joints between panels are sealed with silicone from the outside.

Escola Gerbert d'Orlhac in Sant Cugat, Spain, was built in 2003 using this technology. Designed by the architectural firm Pich-Aguilera Architects, the building has precast concrete modules, hollow-core slabs, and precast concrete frames in some facades. Slabs are 30 cm thick (12 in.) and span up to 11 m (36 ft). Facade panels have painted smooth surfaces. Its distribution respects the structure's scheme. Room modules define small spaces, such as bathrooms and kitchens, while classrooms and open spaces are located in the free structural space between modules. The school measures 3244 m<sup>2</sup> (34,918 ft<sup>2</sup>) and cost \$5.1 million (in today's dollar value), or \$1572/m<sup>2</sup> (\$146/ft<sup>2</sup>).<sup>7</sup> This building illustrates that this technology has excellent results when the school's design is adapted to it. If small rooms are built with room modules, the other parts can occupy the spaces between modules, where no structural walls or columns interfere with the resulting spaces. However, these room modules are expensive and are not able to adapt or change.



Escola Vinya del Sasret in Sant Esteve Sesrovires, Spain, was built in 2005 using precast concrete structural walls and slabs. It was designed by the architects J. A. Alonso and J. Abulí. The site is inclined, so it has a volume with different levels to minimize its environmental impact. **Courtesy of Oriol Pons.**

### Precast concrete structural walls and slabs

Precast concrete structural walls and slabs were used to build many Spanish residential blocks during the 1990s but have rarely been used to construct schools. Only two schools, in Catalonia, have been prefabricated using this technology.<sup>13</sup>

This system's structure uses precast concrete structural walls and unidirectional slabs. Walls are either load-bearing or non-load-bearing. They are massive precast concrete panels 12 cm to 20 cm thick (5 in. to 8 in.) with a surface area measuring a maximum of 3.5 m × 10 m (11 ft × 33 ft). The external walls define the facade, and they are available in different surface finishes: acid etched, sandblasted, and formliner.<sup>14</sup> Several precast concrete unidirectional flooring systems are possible: hollow-core slabs, unitized slabs, and solid slabs. In this method of construction, slabs span up to 6 m (20 ft).

Joints between walls have welded steel pieces and are filled with low-retraction cast-in-place mortar. Connections between walls and slabs are built on-site with reinforced concrete. Tongue-and-groove joints between facade panels have their outside part sealed with silicone and their inside part with mortar. An interior chamber evacuates any water that filters inside.

Escola Vinya del Sasret in Sant Esteve Sesrovires, Spain, was constructed in 2005 using this technology. It was designed by architects J. A. Alonso and J. Abulí. The site is inclined; therefore, it has a volume with different levels to minimize its environmental impact. It

measures 3100 m<sup>2</sup> (33,400 ft<sup>2</sup>) and cost \$5.8 million (in today's dollar value), or \$1875/m<sup>2</sup> (\$174/ft<sup>2</sup>).<sup>7</sup> The building's structure is composed of 14-cm-thick (5.5 in.) load-bearing longitudinal panels and 12-cm-thick (5 in.) bracing transversal walls. Floors are 30-cm-thick (12 in.) hollow-core slabs with a 5-cm-thick (2 in.) cast-in-place concrete topping layer. Facade panels have a lightly sandblasted finished surface. This method has been difficult to use in school buildings. In residential blocks, it works perfectly because walls define facades and interior partitions, avoiding columns in the middle of the rooms. However, schools require open facades and community areas, which are difficult to achieve with load-bearing wall technologies.

### The best method

The framed structure method is the best precast concrete technology for building schools. Its structure is the most adaptable to educational functional programs. Schools designed with this technology do not have structural walls. Therefore, walls can be freely distributed inside a building and in its facades, which can have openings of all shapes and sizes. Moreover, walls can be moved or replaced if the building's use changes. Consequently, 90% of precast concrete school buildings have been constructed using this technology, whose numerous suppliers offer tight budgets and limited time frames.

The best school buildings have been built employing this framed structure method. Recently built schools,



Escola Can Juncadella in Sant Vicenç dels Horts, Spain, was built in 2009 using precast concrete frames, hollow-core slabs, and facade panels. It was designed by J. M. Fort. **Courtesy of Oriol Pons.**

such as Escola Juncadella, meet the latest requirements in terms of quality, comfort, and sustainability. All of their precast concrete components have been successfully produced and assembled following required quality controls. The exterior building envelope has continuous insulation, which avoids thermal bridges, in both facade and roof surfaces. Heating and cooling system ducts have been integrated inside the ceiling and the interior walls. External sun shades, natural daylight, and natural ventilation provide comfort to educational spaces without any energy costs. A solar thermal system heats water, and a rainwater harvesting system can be used to flush toilets.

Three main requirements should be followed when building schools using precast concrete technologies: flexibility, sustainability, and improved components and connections.

### **Flexibility**

The buildings should be more flexible in the ways that it can be used. Schools will need to be able to easily change distribution, use, or even site. Education laws and theories evolve constantly, and schools have to adapt to them. The number of students enrolled in any school changes depending on unpredictable factors, such as demographic rates, migration, and natural disasters. Current precast concrete school buildings have resolved the need for more schools. However, what happens when a school needs to be reduced in size or is no longer necessary? A school building could be converted to a new use, such as a home for the elderly. In this case, the original building must be flexible enough to change its distribution. A school could be disassembled and moved to a new site, or perhaps to a storage space until a new use is determined. At the storage location, it might even be possible to refurbish it in order to meet the latest standards.<sup>15</sup>

### **Sustainability**

Buildings must meet the highest sustainability requirements. The whole life cycle of these precast concrete school buildings should improve, from their design to their demolition.

During its design, many inputs should be considered, such as the use of recycled concrete and maximizing the use of natural light.<sup>16</sup> During production, transportation, and assembly, energy consumption should be reduced by using more efficient and environmentally friendly machinery. During the building's use, the school's staff should be able to control the building's services in order to optimize their consumption. Building services should have a low environmental impact. The amount of water used could be minimized by collecting rainwater with specially designed precast concrete roofs. These roofs' components could also include photovoltaic or thermal panels installed at the factory. Facade panels could also incorporate passive solar systems.<sup>17</sup> During refurbishment or demolition, school building components should either be reused in other buildings or recycled in the production of new components.

### **Improved components and connections**

In addition, the technology of school buildings' components and connections should be improved in the following ways:

- Improve components by using better materials, such as cement with low carbon dioxide emissions and recycled aggregates.
- Incorporate ducts, thermal and acoustic insulation, finishing surfaces, and photovoltaic cells into components before they leave the factory.
- Reduce and optimize components' cross sections and weights. Make connections dry and reversible so they will be more flexible.

- Analyze cost.<sup>7</sup> Precast concrete schools should only cost more if the latest technologies have enough added value.

## Conclusion

Spain can be proud of the precast concrete school buildings constructed since 2002. However, building technologies everywhere must progress in order to improve future schools. The best technologies will be those that meet previously listed requirements and anticipate other requirements yet to come.

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