

# Technical-Scientific Support for the Definition of the Project for the Reconstruction of School Buildings Involved in Seismic Events



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**Abstract** This research regards the development of the project of the new school of San Severino Marche. The school is located in a region severely affected by the earthquake, and for this reason the design of the new building was based on a high degree of structural capacity, as well as strong innovations on typological and technological level, in accordance with specific educational needs. The research work is developed through a BIM approach that allowed the proper coordination of the disciplines involved.

**Keywords** Reconstruction · School building design · Information modelling · Seismic design · Design process

## 1 Introduction

This research work is part of the programme set by Government Commissioner for the reconstruction of areas affected by the earthquake of August, 24 2016, in the framework of the Memorandum of Understanding between the Commissioner and the Conference of Rectors of Italian Universities.

The research steps carried out aimed at facilitating all the project activities, in order to reduce times of project development, and to reduce construction times of heavily damaged buildings. At the same time, the goals of this research include the coordination of advanced disciplinary skills, leading to the design and construction of new buildings with a high degree of structural capacity, as well as strong innovations on typological and technological level, in accordance with specific educational needs. The remarkable research work is based on the use of a BIM approach

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and methodology, in order to optimize the coordination of the various disciplines involved.

The project area assigned from the Conference of Rectors to the research group referring to ABC Department was the most challenging, due to its extensions and to project costs, among all the work programs defined in the Memorandum of Understanding. For this reason, the engagement of a multiplicity of available professionals with different skills was crucial to guarantee the quality of the intervention. The project activities were carried out with the collaboration of Area Tecnico Edilizia, the technical office of Politecnico di Milano.

The project activities, carried out in 2 months, required the definition of all the contents of concept and developed design. Flexibility was a primary aspect of the project development, allowing for potential future adaptation of functional and organizational layouts. Another relevant concern was seismic vulnerability, related to the special conditions of ground acceleration of the area, managed through innovative construction techniques. The use of dry construction systems helped in both these aspects, implying—in addition—high-performance levels in terms of energy consumptions reduction, in the context of optimization of circular economy concepts.

The Technical Institute E. Divini is a relevant institution in the region, as it provides advanced technical education to professionals in an active manufacturing environment, located in Macerata province. Before the earthquake, the institute hosted five specializations, divided in 32 classes, resulting in the total amount of 657 scholars, with a growing trend.

The amount of scholars used for the project development, defined by the Provincia di Macerata for the reconstruction, was set on 800 scholars. Considering this requirement, the project choices led to the definition of a building with a volume of 47.177 m<sup>3</sup>. The previously existing building had a volume of 39.000 m<sup>3</sup>.

The new designed building will stand, together with the laboratories that are currently under construction, in the linear part of the area, located near Viale Mazzini. The main part of the building will be located in the Southeast-corner, between Viale Mazzini and Via Monte Conero, near the Sports Center.

Several aspects guided the project concept and building layout: the morphology and geometrical features of the area, the optimal solar orientation, and, most importantly, the opportunity to create a building that could act as a landmark, in the corner of the urban block. This space was previously marked by an indefinite cluster of volumes, lacking of organizing approach.

The integration and coordination of different competencies and skills was possible thanks to a BIM-based approach.

The presented project work can be seen as a relevant case study for future research collaborations, with the goal of supporting project activities related to emergency conditions. Disastrous events, such as earthquakes, require in fact well-timed interventions, but also the adoption of innovative strategies.

## 2 Information Modelling Approach

The information modelling strategy of the new buildings was guided by four main approaches:

- Compliance with regulatory and legislative consistency (DM 1975);
- Contextual modelling on various discipline’s models, due to the connection among them;
- Coordination and management of clashes between elements and components of the various disciplines involved;
- Coordinated export of project drawings and documents.

The number of models created for the entire school building is eight:

- 1 architecture model for each building (A-School building and B-Gym);
- 1 structural model for each building;
- 1 building systems model for each building;
- 1 mass model for the third building (building C), hosting laboratories, that is already under construction. This building was modeled as a unique volume, as it is not part of the contract. This building was anyway taken into account during architectural design in terms of space distribution and volume management of the entire building site.
- 1 Master model, where all the models are linked. The Master model also includes the surroundings and the external areas of the buildings.

Considering technical systems, only HVAC systems are modeled, excluding therefore water related systems and electrical systems; this choice is due to the larger dimensions of HVAC ducts.

The three models of building A and building B have been linked before being inserted in the master model, in order to allow clash detections among the elements of the different disciplines. For this reason, the structural model is linked inside the architectural model, and then linked inside the building systems model (Fig. 1).

The information modelling operations of the buildings allows to take advantages of all the potentials of this approach from the early stages of design (Di Giuda and Villa 2016). The model has been gradually detailed during the process, from concept design to technical design.

In concept design, the project idea was translated from freehand sketches to models. The first step regarded the production of mass models representing the buildings’ volumes integrated in the existing context, taking into account site layout and



**Fig. 1** BIM model (architectural, structural and building systems models) of building A—School

altitudes. This operation was useful to develop the best-fitting shape of the buildings in relation with the surroundings, the solar path, and the shading patterns. A second step regarded an analysis of the relation between the new buildings and the existing one (building C), defining the distribution of internal spaces. The internal layout was carried out based on minimum surfaces, orientation, and connections with the central building hosting laboratories.

The second phase of the project regarded the progressive development of details in the models through the integration of technical elements (façades, roofs, vertical walls, and horizontal slabs) and spatial elements, such as rooms. Considering minimum dimensions of spaces, the specific requirements and legislative standards were taken into account.

During the project development, areas and volumes of the rooms were often changing due to the moving of internal walls and the changes in thickness of load-bearing walls. Nonetheless, the use of BIM approach and code-checking allowed to control rooms' areas, guaranteeing a continuous check of minimum surfaces (Tagliabue and Villa 2017). This control was carried out through tables in the BIM-based software, where calculation rules facilitate the checking of parameters and variations (Fig. 2).

Interoperability between Autodesk Revit and Midas Gen, a software for structure calculation, have been tested. Non-graphical documents, such as bills of quantities, have been exported through Quantity Take Off from the BIM model.

Render images were realized using 3ds Max, exporting from Autodesk Revit and choosing materials and textures for objects and surfaces (Fig. 3).

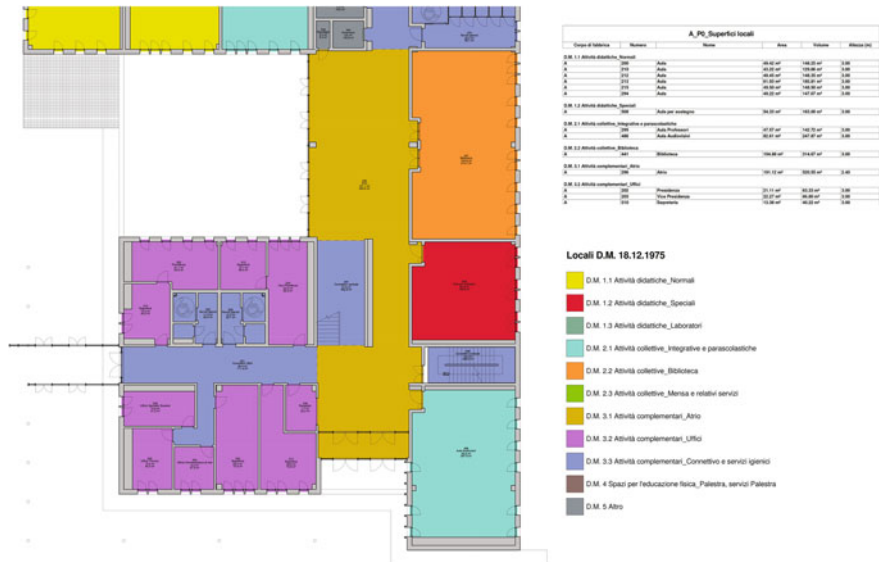


Fig. 2 Automatic control of areas in the BIM model



**Fig. 3** Render image of the main entry

The use of BIM modelling resulted therefore in several advantages: the continuous control over the intervention's budget, the comparison of different layouts, the iterative approach to project design, and finally the fulfillment of a balance between the Client's requirements and the total cost of the building (Eastman et al. 2018).

### **3 Structural Design**

#### ***3.1 Objectives and Design Criteria***

The following are the guiding principles and the innovative techniques that inspired the design of the structures of the new ITIS Divini School, in San Severino Marche. The performance requirements considered in the structural design have concerned both the need to optimize construction times and the seismic safety requirements, dictated by the knowledge acquired on the local seismic hazard (Fig. 4) and by the will, given the frequency with which important seismic events are repeated in this area, to minimize the effects of damage to the structures, according to more rigorous multilevel performance, required by modern seismic design. The project involves the construction of two buildings. The first (main building), containing classrooms and laboratories, has a C shape in plan. The second, constituted by the gym with attached changing rooms and services. For brevity, we refer here to the main building only.

The San Severino school reconstruction project has been developed considering materials and techniques that optimize the fulfillment of the objectives of:

- rapid construction;
- recyclability of the components and basic materials;
- durability of the materials;
- maintenance costs minimization;
- low construction costs (contents within 1100–1200 €/m<sup>2</sup>).

The design solution, in addition to fulfilling these objectives in the best possible way, was strongly conditioned by the following constraints:

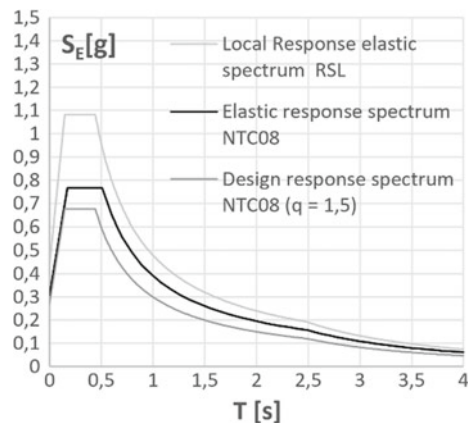
- the connection with the project of mechanical Laboratories already in a construction phase;
- the availability of an underground level (given by the demolition of existing buildings).

The reference parameters for the seismic design are the following (NTC 2008):

- Seismic area: II
- Class of use of the structure: IV
- Nominal design life  $VN = 50$  years
- Importance factor  $C_u = 2$  (buildings with strategic functions)
- Reference seismic life ( $VR = VN C_u = 100$  years)
- Ground type: C
- Topographic category: T1.

The definition of the design seismic actions to be adopted was refined through the analysis of local seismic response, carried out on the project stratigraphy. This analysis led to the definition of the SLV response spectrum shown in Fig. 4.

**Fig. 4** Design response spectrum



### 3.2 Description of the Structures of the Main Building

The structure was based on a system that would allow to have the advantages of using reinforced concrete precast elements and assembling by components, similar to metal structures (Acito 2019).

The structural system was chosen in order to best optimize the objectives of points 1–5 and the constraints of points 6, 7 of the previous paragraph (Acito and Lavermicocca 2019).

The assumed system uses as a seismic-resistant system (Fig. 5), a classic structural system with post-tension pre-stressed reinforced concrete (p.r.c.) shear walls (Fig. 5).

The structural system is completed with the use of linear structural elements and panels, partially or totally pre-casted, which in the assembly phase guarantee an adequate self-supporting capacity for the construction phases, designed for vertical loads only (Acito and Jain 2019).

In particular, the structural system assumed for the structure is currently provided by prefabrication companies in the sector, with different commercial names, for which the structural elements differ only in some detail aspects. The innovation introduced in this project, perhaps for the first time in Italy, is linked to the idea of resisting the seismic actions with the only p.r.c. shear walls, designed for the realization of stairwells, whose geometric and mechanical consistency was found to be adequate only thanks to the introduction of post-tension (Acito and Chesi 2019). In the specific case, the assumed system uses the following structural components:

- seismic-resistant walls in p.r.c. (Fig. 5);
- precast columns in c.a.;
- alternatively, partially precast columns could be used, made with reinforced concrete filled steel tubes columns (RCFST). In which the concrete reinforcement is designed to withstand the vertical design actions and the steel tube designed for the construction phase actions and for the fire resistance (Circolare n.617 2009);
- composite steel-concrete beams, partially pre-casted with the designed reinforcement for self-supporting in the various construction phases;
- decks made with pre-stressed self-supporting hollow core panels on the entire length, for all the construction phases (Fig. 5).

The design was developed in the final design following the procedures of the integrated design in the BIM environment. The structures were calculated using the Midas Gen. software (Fig. 6).

## 4 Building Services

One of the main design purposes was the limitation of the building energy consumption through the use of high performance envelopes, high-efficiency HVAC (Heating Ventilation and Air Conditioning) systems and by the exploitation of renewable

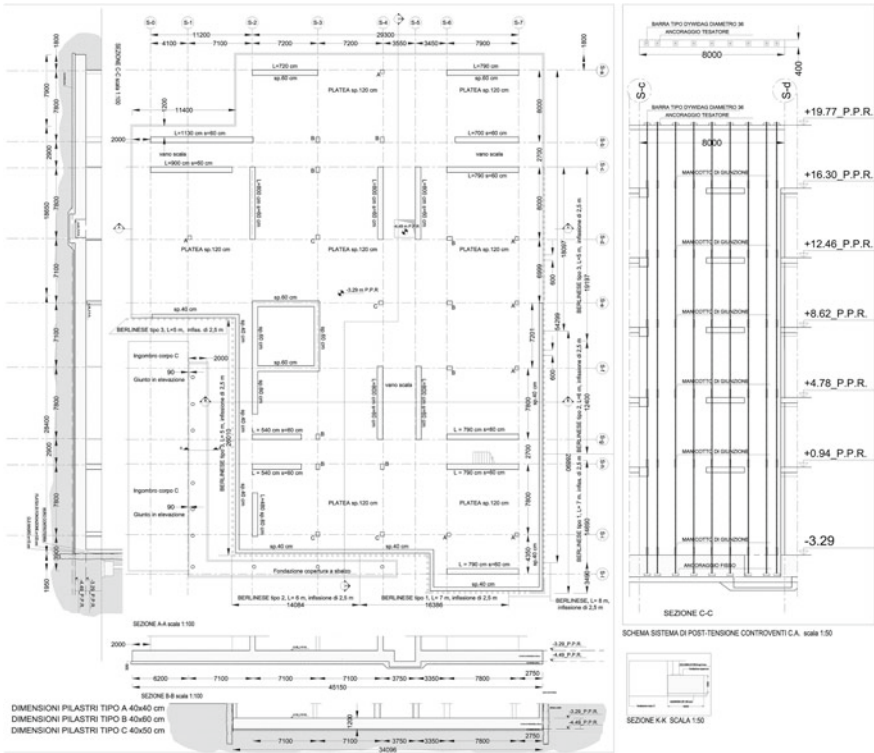


Fig. 5 Structural system: a Foundation plan; b Post-tension scheme of the shear walls

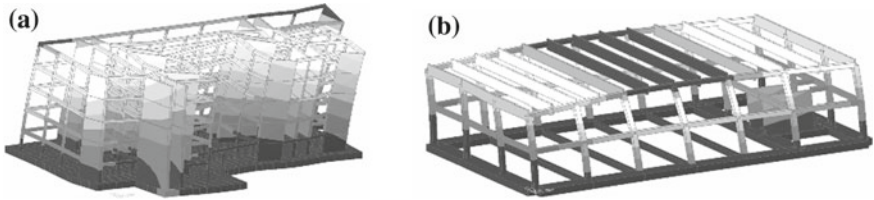


Fig. 6 Numerical models: a Numerical model of the main building; b Numerical model of the gym

energy sources. In this regard, the building services design of the Divini Technical Institute was oriented towards integrated solutions able to guarantee a high environmental comfort with a minimum amount of non-renewable primary energy, providing an efficient use of energy resources and optimal indoor conditions according to outdoor climate, crowding, equipment use, etc.

In detail, the generation system consists of two high efficiency hybrid air/water compression heat pumps, equipped with a total heat recovery system. One of such heat pump is fully dedicated to the air conditioning system, while the second one is used for



heating purposes but with priority to domestic hot water (DHW) production. These units are equipped with a primary air exchanger and a secondary water exchanger, that can be connected to a ground water source or to solar thermal collectors if necessary, further increasing the overall system efficiency. Furthermore, a considerable part of the electricity demand of the heat pumps is generated by a photovoltaic system installed on the building.

Classrooms and offices are equipped with low-temperature and low-inertia radiant panels. In this way, it is possible to easily obtain both indoor comfort conditions and high energy efficiency, with a particularly low environmental impact. This is achieved also through a dedicated building services control and management system, monitoring internal conditions, external climatic variables and actual occupation of the spaces in real time.

According to the most advanced guidelines, the HVAC system has been designed to ensure the highest flexibility, with solutions that allow to obtain optimal thermo-hygrometric conditions with low installation costs. The AHUs (Air Handling Unit) are characterized by a high-efficiency heat recovery system, both static and thermodynamic, and by an adiabatic-type cooling (and humidification) system. They can operate at variable flow rates by modulating the fan rotation speed, in order to maintain a constant pressure/depression in the supply/return ducts according to the number of the served classrooms. This because the air conditioning of each classroom can be activated or deactivated at any time according to the effective need. This solution introduces a significant energy saving since, typically, the occupation profile of classrooms can be different.

The supply and return ducts layout has been integrated in the BIM model, in order to identify and eliminate any interference with structural and technological systems. This because the building systems' integration had to achieve two main goals:

- the functional coordination of the various technical subsystems in order to optimize the overall performances and their control;
- the spatial coordination of the various subsystems, to simplify their installation, accessibility and maintenance, in coherence with the needs of the periodic total or partial replacement of their components. In this regard the use of BIM becomes fundamental.

Furthermore, all the mechanical systems are controlled by a supervision system. The objectives of the centralized regulation and supervision system are the following:

- reduce the building services management costs;
- ensure a continuous building services monitoring;
- increase the overall efficiency and service life of the system, supporting a scheduled and preventive maintenance (thus reducing to a minimum the possibility of failure).

Therefore, the choice of all the mechanical systems was carried out with the aim of optimizing the energy performance of the building, but also of making the systems extremely reliable, competitive and monitorable, as required by the particular building use. Finally yet importantly, the use of advanced and modern technologies, their integration into the building, as well as the use of renewable energy sources,

take on a significant educational and application function, especially in a technical school.

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