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THE NEW ARPA RESEARCH CENTRE IN FERRARA: composite wood panels in non-conventional timber structures

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ABSTRACT: The new Arpa research centre, currently under construction in Ferrara (Italy), represents an interesting example showing how composite wood panels and standard glulam elements can be combined to ensure structural efficiency and elegance. This building has a single storey structure with a complex, technological roofing system, it covers an area of about 3200 m^2, and reaches a maximum height of 12.80 m. Its modular composition is obtained assembling multiple chimneys of different heights, equipped with built-in photovoltaic systems or with windows which can be automatically oriented according to specific day-lighting techniques.
The final solution matches the design goals by solving geometrical complexity into an efficient manufacturing and assembling scheme. Every chimney is subdivided into standard composite wood elements, obtained combining a core timber frame with two stiffening OSB panels, while the remaining structural members are designed using standard glulam beams and columns.

KEYWORDS: Wood panels, Non-conventional structures, Sustainability

1 INTRODUCTION [123]

It is general belief that structural designers give form to objects that are of relatively large scale and of single use; these designers see forms as the means of controlling the forces of nature to be resisted. Architectural designers, on the other hand, give form to objects that are of relatively small scale and of complex human use; these designers see forms as the means of controlling the spaces to be used by people. From this point of view the prototypical engineering form, the public bridge, requires no architect, and the prototypical architectural form, the private house, requires no engineer.
Nevertheless, structural engineers and architects must collaborate and learn from each other when, as with big buildings, large scale goes together with complex use. In the last decades, in fact, it has become clear that the problems related to buildings' design concern various topics besides the mere structural stability. The quality of public life depends on the quality of civil works and, as a consequence, advanced technological performances, aesthetics pleasantry, good materials, proper durability, shorter construction times and high sustainability, represent nowadays widely diffused requirements. On the other hand, modern buildings are often designed with flexible, articulated and complex architectural shapes, requiring "ad hoc" non-standard solutions which can lead to a problematic increase in the final cost. **For all these reasons, nowadays structural designers are called to face the exiting challenge of producing high performancing, innovative buildings, keeping in mind not to waste public resources.**
In this contest, the new Arpa research centre, currently under construction in Ferrara (Italy), represents an interesting example showing how timber structures can be successfully employed to ensure an efficient, cheap and elegant solution.

2 BUILDING DESCRIPTION

In 2008 an International Competition was held for the architectural and structural design of a 5000 m^2 complex to accomodate new ARPA's offices and laboratories. The whole project require to consider both the renovation of an old reinforced concrete construction and the design of a new building, directly connected with the existing one by means of a light steel-glass "sail". In particular this paper is focused to the description of the research centre's timber structure, which covers a total surface of about 3200 m^2.
The main client for the job is a regional public agency (in fact ARPA stands for "Agenzia Regionale Per l'Ambiente"), and its main request is to have a workspace characterized by high architectural and environmental quality, low operating costs and the maximum level of **sustainability**. In brief, the word

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sustainable, conveys the idea that technology should rely on non-exhaustible energy sources that do not wreak irreparable damage to nature's delicate balance and, at the same time, deliver performance and comfort levels comparable to those obtained with conventional technologies. The crucial issue of the project, therefore, is the yardstick with which to define what technologies really generate effective cost savings. The final solution adopted to reach design goals is shown in **Figure 1**, where the rendering of the building's final configuration is presented:

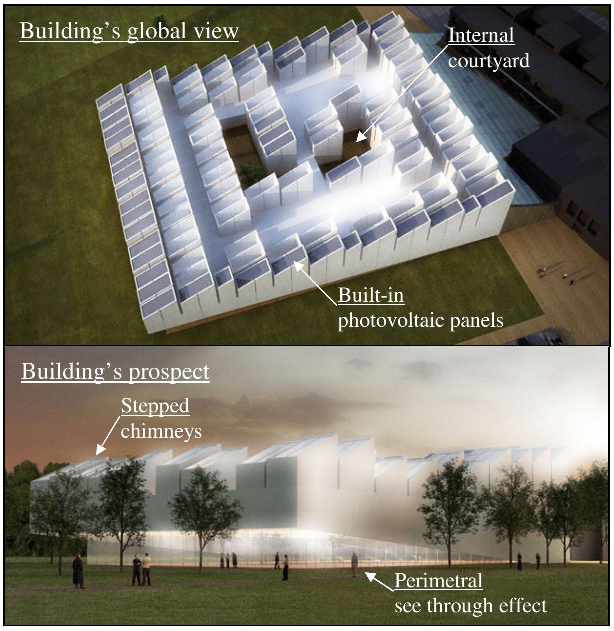

***Figure 1:** Rendering of the building's final configuration showing chimneys' arrangement;*

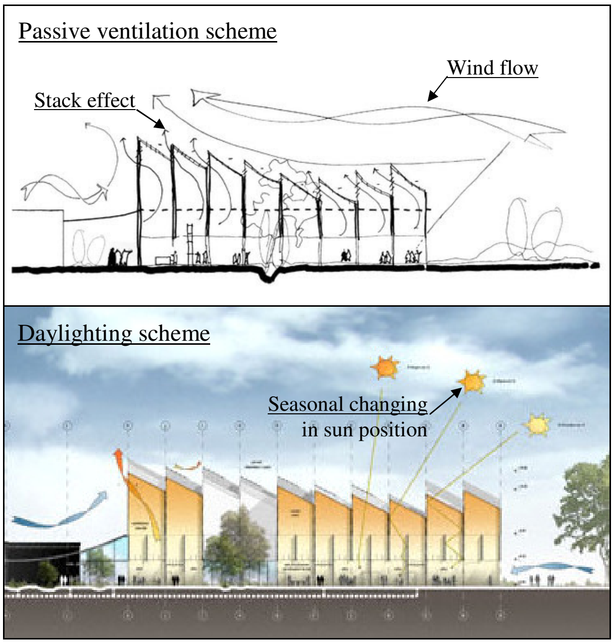

***Figure 2:** Reference sketches for lighting and ventilation techniques adopted in the building;*

In brief, the research centre is a single storey structure with a complex, technological, roofing system (that is the so-called fifth façade), having a simple rectangular plan (of about 51 x 62 m) and reaching a maximum height of 12.80 m. A series of stepped chimneys give the building an innovative and pleasant visual appearance assuring, at the same time, a strong architectural identity. These elements are equipped with built-in photovoltaic panels or with automatically moved skylights. Their main function is to produce on-site renewable energy, or to promote not only day-ligthing, but also natural ventilation (as effectively shown in **Figure 2**, where two interesting sketches regarding day-lighting and ventilation strategies are presented). Individual controls are also provided, to improve as far as possible indoor environmental quality, assuring a good microclimate condition and an efficient lighting control.
The hub of the building is constituted by an **internal courtyard**, where native vegetation is bedded in to provide green open space for both research workers and visitors. In fact, the final layout chosen for the laboratories has been defined keeping in mind that occupant well-being perception can be improved by providing views to the exterior landscape. For this reason all the workspaces are open to the outside, ensuring an alternation of solid & void, indoor & outdoor, and also micro-environments that break up and define the research centre's volumes. Due to its innovative approach, this building has been the **winner of the Architectural Review MIPIM FUTURE PROJECT AWARD in the sustainability category**.

3 THE STRUCTURAL SOLUTION

Considering the peculiar building's shape, the main design challenge has been to find a structural solution which could split the compound into multiple standardized elements, easy to manufacture, to carry on site and to install. For this reason both standard glulam elements and composite wood panels have been employed for the final layout.

3.1 COLUMNS

Columns are the only vertical members which connect the reinforced concrete foundation system to the main deck level, where chimneys are installed. This structural choice qualifies the building from the architectural point of view, because it generates a "floating-roof" effect with a consequent see-through perception of perimeter surfaces for a total height of about 4.00 m.
Basic requirements for these elements are minimum dimensions (only 28 x 28 cm section allowed) and, as a consequence, high strength performances. For this reason GL36h strength class glulam (according to EN 1194) has been chosen in the final solution.
Finally the beam-column connection and the base joint between the pillar and the foundation system, are obtained coupling two specific welded steel assemblies with standard 4.8 class bolts. **Figure 3** shows the typical solution adopted to simulate the boundary conditions assumed in the structural analysis.

3.2 MAIN DECK

The main deck is located at columns' top section, about 5.00 m above the base floor of the research centre. Its key function is to carry the chimneys which define the roofing system, but it also contains some useful flat surfaces, dimensioned expressly to accommodate all the technological equipment required to accurately control heating, ventilating and air-conditioning of the whole building.

From the structural point of view, the main deck is composed by a principal and by a secondary framework. The first one is made using coupled glulam beams (2 girders 20 x 60 cm) GL28h strength class (according to EN 1194). These elements run parallel to the shorter side of the building, have a maximum transportable length of 12.00 m, and hold the equipment required to fasten the chimneys, the horizontal bracing system, and all the secondary framework's members (only standard screwed steel connectors have been used). The span adopted for calculus purposes is 6.00 m.

The secondary framework, instead, is obtained coupling 20 x 60 cm and 10 x 18 cm glulam GL28h beams, which realise the flat surface required for the installation of technological equipment.

An helpful reference to understand structural layout is presented in **Figures 7** and **8**, where two remarkable sections clearify the structural layout.

3.3 CHIMNEYS

Chimneys are the most representative elements in stressing the New Arpa research centre's peculiarity, not only from the architectural point of view, but also from the structural point of view. For this reason they are described more in depth than the remaining building components.

More precisely, the roofing system is composed by **113 chimneys of different height**, arranged to guarantee an efficient solar gain for the built-in photovoltaic modules and the best possible lighting exposure for the skylights. These elements have a plan size of about 3.00 x 6.00 m and are individually conceived to achieve a maximum level of standardization.

The main design idea is to split every chimney into 3 typological elements: the hat, the basis and the connection. The first two ones are composed by 4 panels, having the same geometrical characteristics for all the chimneys. The third one, instead, is built using 4 panels of variable height, depending on the specific element considered. This approach is very convenient, because it allows to subdivide the structure into a limited number of standard elements, easy to manufacture, to lift and to transport. The advantages for the builder which come from this project modality are very significant and fully justify the time spent for the design stage (this activity, in fact, is very demanding, and requires to draw 58 different cross sections to completely define all meaningful parameters).

The step that follows the building's geometry definition is then the choice of the **best technical stratagem to use in manufacturing, assembling and fixing the panels in their final position**.

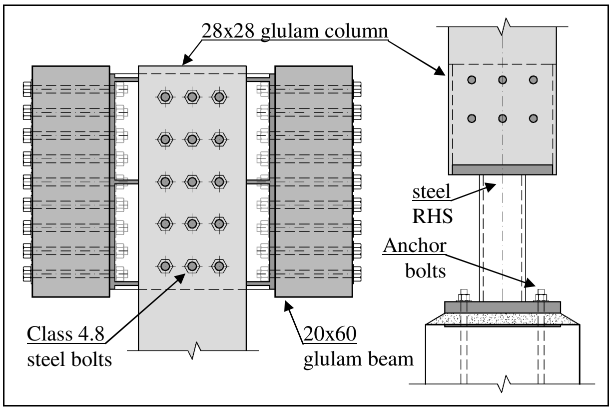

Figure 3: *Details of column connection (a symmetric layout of the joint is considered in this figure)*

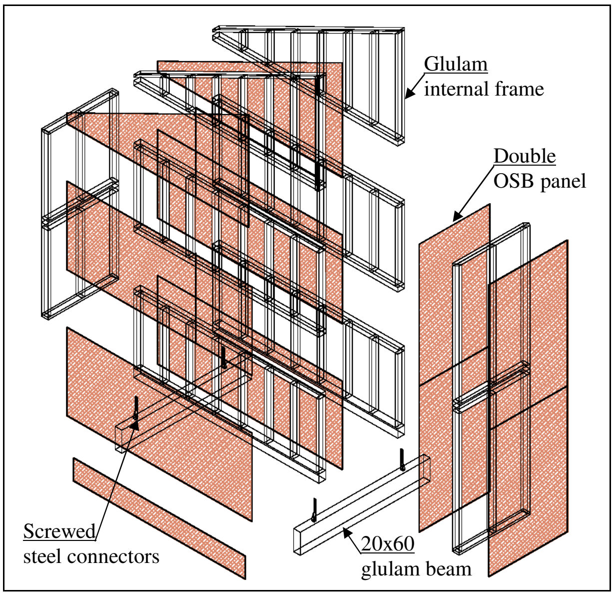

Figure 4: *Exploded view of chimneys' components (only half of the total OSB panels are shown for clarity)*

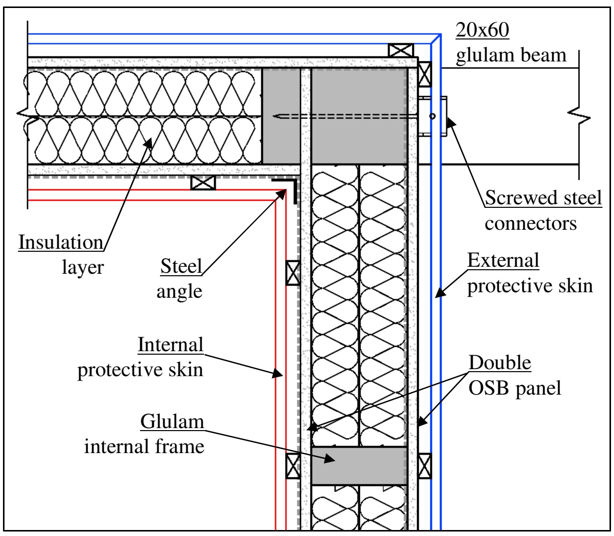

Figure 5: *Chimney's corner detail with lateral screwed connections and protective skins (internal and external)*

The final solution, as previously mentioned, adopts a **glulam internal frame, wrapped between two sideways nailed OSB layers,** for each element. The panels are directly connected on site, using crossed screws (at both vertical and horizontal interfaces) and steel angles. The whole chimney structure is finally lift and fastened on the principal framework, through specially designed connectors. A useful reference to understand the former description can be represented by **Figures 4**, **5** and **6**.

Apart from all the information presented until now, the chimneys can be subdivided into two fundamental typologies: **the "hot" ones and the "cold" ones**. The first group is defined by the elements equipped with a double layer insulation stratum (consisting of 10 cm with ρ = 160 kg/m^3 and 10 cm with ρ = 270 kg/m^3), built with wood-fiber panels, and reaching the high energetic performances required for the right building's behaviour. The second group, instead, is defined by the 39 elements arranged to cover the external perimeter walkway, which has no insulation requisitions.

From the **structural point of view** the panels show a different behaviour in the two main orientations.

Elements disposed along E-W direction lay directly on principal framework and bear only wind pressure. Elements oriented in N-S direction are simply supported by the coupled 20 x 60 cm glulam beams and can be assimilated to composite girders in which the tension and the compression chords are the glulam components of the internal frame, while the two webs are the nailed OSB panels.

Details regarding the different solutions adopted to conjugate roofing system's complexity with a rational layout for rain water channels, and regarding the two skins used to protect structural elements from the atmospheric attack, will be presented at Point 4 of the present paper.

3.4 BRACING SYSTEM

Horizontal and vertical steel elements have been introduced to provide the required capacity and stiffness to resist seismic action, wind pressure and loads due to imperfections.

The main challenge in defining the final building layout is due to the limitation to the total number of visible structural members, and to the **necessity of completely avoiding horizontal bracings in the body of the chimneys** (this requirement is of paramount importance because the intention of the architect is to give the feeling of uninterrupted vertical "wells of light" and, for this reason, horizontal crosses cannot be placed).

These requisites are quite restrictive and involve an assembling of elements under the flat surfaces dimensioned to accommodate the technological equipment. The problem connected with this solution is that the structure has no global plain rigid diaphragm, and, for this reason, every alignment is independent from the surrounding ones.

As a direct consequence, special care has been paid to the choice of the most convenient position for vertical bracing members, in order to avoid all the possible dangerous labilities.

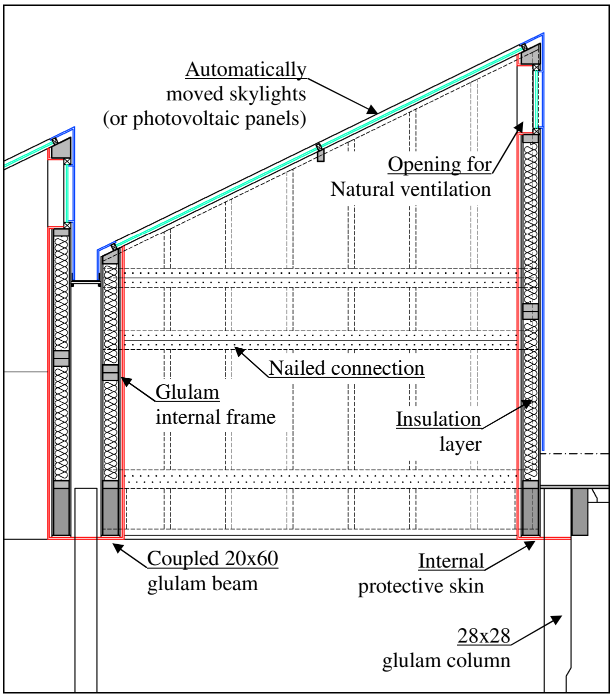

Figure 6: *Main section of a typical chimney showing the partition in standard prefabricated panels (all significant details have been highlighted)*

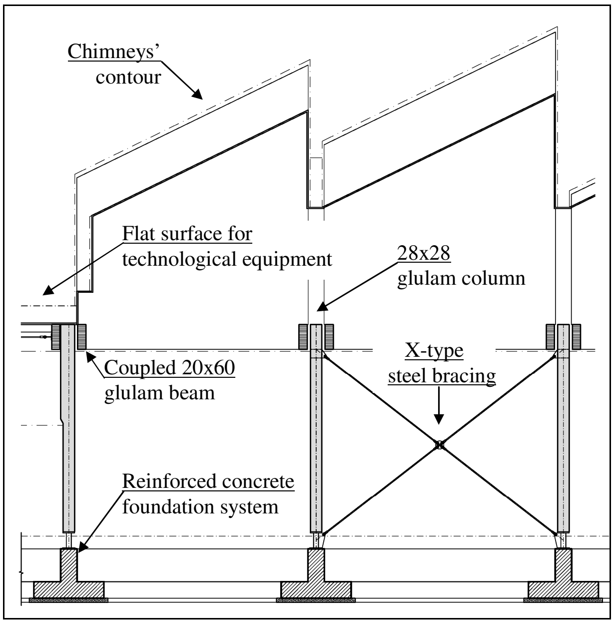

Figure 7: *Solution adopted for the main bracing system (only X-type configuration is shown above)*

The final solution satisfing these boundary conditions uses horizontal crosses (ϕ24 steel bars grade S460JR) and vertical elements having an X-type or a K-type configuration (also these members requires ϕ24 steel bars grade S460JR). The bracing system design makes the hypothesis that only tension members are effective in each direction.

An helpful reference to understand the structural layout is presented in **Figure 7**, where the X-type steel bracing is clearly shown.

3.5 SUSPENSION SYSTEM

The plan of the building provides a strong connection between interior and exterior areas. More in detail this approach requires **covered perimeter walkways** along 3 of the 4 research centre's sides (the remaining face is directly connected to the existing building through a light steel-glass "sail").

Under the structural point of view, Est and West walkways do not imply technical difficulties because the required cantilevers have a total length of only 3.00 m, and can be obtained simply extending the principal glulam coupled beams. In the South side, instead, the configuration is more complex, and requires a cantilever of over 6.00 m perpendicular to the main deck's girders. The final solution foresees a **suspension system** in which the vertical member is obtained using a tapered column, the steel tension rods are realized through hollow section profiles (ϕ 101.6 x 8 grade S355JR), and the compression member is manufactured with two 30 x 42 cm glulam beams GL28h strength class (according to EN 1194). Furthermore, these elements are directly connected to the pillars by a strong bolted joint, designed to sustain loads due to seismic inertias and wind pressures.

This structural layout is very effective and assures an high stiffness to both vertical and horizontal forces. The final solution is clearly represented in **Figure 8**, where the first two rows of chimneys are shown, completely characterizing the suspension system.

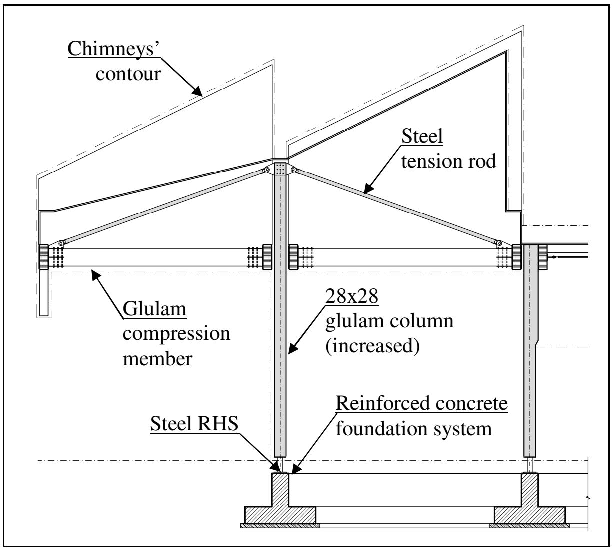

Figure 8: Technical solution adopted for the suspension system required to support the first chimneys' alignment

3.6 LOCAL DETAILING

It is common belief that a good design of prefabricated buildings requires: high accuracy in defining geometrical dimensions, special care in evaluating building phases, and extraordinary precision in local detailing. In this paragraph two remarkable cases will be presented: the asymmetric bearing configuration for the side columns, and the symmetric solution adopted for the small corner pillars (make reference to detail in **Figures 9** and **10**).

The asymmetric bearing is applied in correspondence to the North side of the building, and is designed to assure an efficient support to the 20 x 60 cm glulam beams (which are not coupled in this alignment). The overturn of the main girder is prevented using two steel bolted collars, designed to resist unexpected horizontal forces. The bearing capacity is fully assigned to the bracket obtained at the column's top section.

Two special kind of reinforcement are required to sustain design loads through **orthogonal tension and orthogonal compression enhancements**. Both of them are realized using WT-T-8.2 screws, having a total length of 190 mm or 330 mm. The joint is finally completed with an additional timber part, which has no structural relevance (it is useful only for accurately fixing external and internal protective skins).

The symmetric bearing is applied at the small corner columns which supports the 20 x 60 cm glulam beams at the internal patios. The solution adopted for this detail requires **4 steel bars anchored using epoxy resins** and completed by a T-shaped element, specifically installed for the bolted connection.

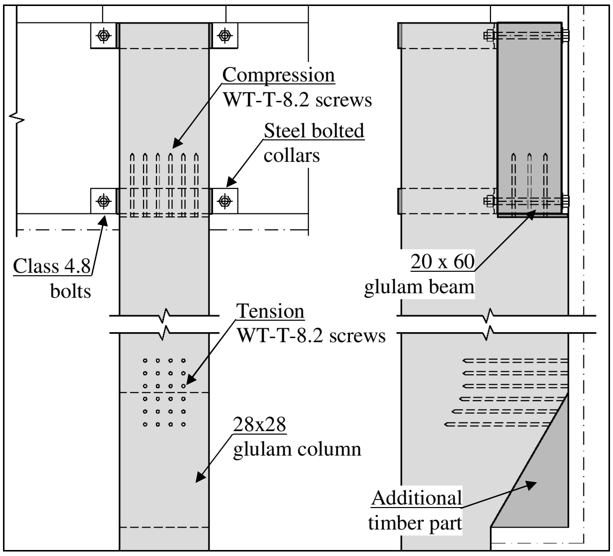

Figure 9: Screw's layout adopted to improve both tensile and compressive strength (asymmetric support)

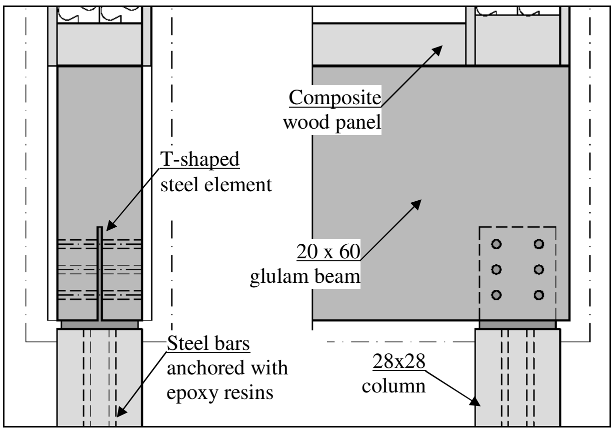

Figure 10: Configuration of beam-column joint referring to epoxy resins employement

4 THE DURABILITY CONCERN

Durability concern represents nowadays an inescapable requirement for every kind of civil work. In fact the real goal that every designer must attain is to realize buildings which can fully preserve their functionality through years, and which do not involve extraordinary repair services. This approach is generally required regardeless the materials used in the construction and is not, like some designers claim, a prerogative of timber structures (also concrete and steel, as widely proved by common experience, require special care under this point of view).

For this reason, the problem of durability has been in depth considered, investigating all the possible damage sources which can be associated with the specific building under consideration. More in detail, this paragraph presents the solutions adopted in realizing the protective skins and the rainwater disposal system.

With regard to the protective skin, it is generally known that some wood species are more appropriate in withstanding the continuous aggression exercised by atmospheric attack (rain, moisture, solar radiation … are all possible causes of deterioration). Considerating the research centre's importance, the design choice assures a total protection of exposed structural elements (primarily beams and panels) by mean of a double skin. In particular the external one, which is in direct contact with atmosphere, is made using red cedar planks, while the internal one, which has only an architectural functionality, is realized through fir plywood panels, treated with a water based white paint.

The choice for the rainwater disposal system is maybe the most critical challenge to face in order to assure a long life to the building. The correct choice of the water channels' layout, actually, is of paramount importance in assuring: an efficient flow towards the specific collecting points, an easy maintenance (full replacement is also considered), and a rational crossing between rain generated streams. An exhaustive geometrical analysis has been done, considering each channel individually.

Unfortunately there is not space enough to present in detail the final configuration with its typical characteristics. For this reason, if you are interested in some additional information, please mail one of the authors.

5 CONCLUSIONS

According to the previous paragraphs, the new Arpa research centre constitutes a meaningful example of a technological structure, built with high quality materials, detailed for proper durability, designed for building-cost containment, characterized by short construction time and streamlined for low operating energy consumption.

The logical conclusion of the paper, therefore, appears to be that modern wood industry provides to engineers an incredible range of innovative solutions which make this material competitive not only for traditional, small-size, residential buildings, but also for the newfangled big structures required to express modern architectural principles.

ACKNOWLEDGEMENT

As already clarified in the introduction of this synthetic paper, the structural design of buildings in which large scale goes together with complex use can not be independent from architectural remarks.

For this reason we particularly thank to **MCA** (Mario Cucinella Architetcts) for the continuous, accurate and detailed support they give us through the various steps of project's development.

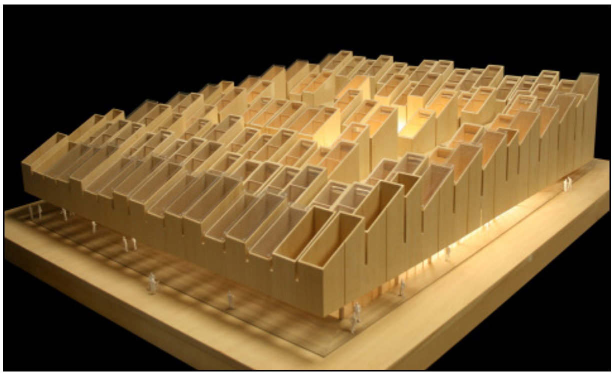

Figure 11: *Small scale model used by MCA for the final study of building's architectural appearance*

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