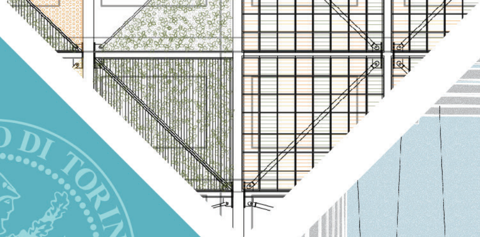
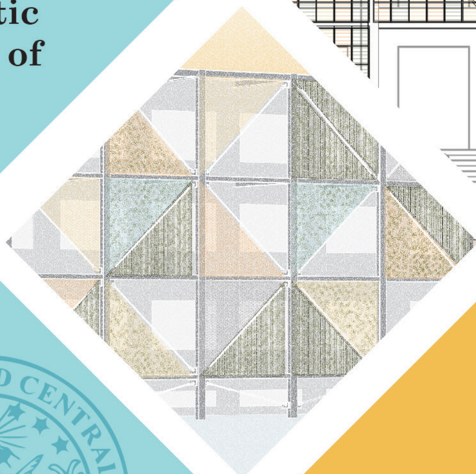


The exoskeleton as an integrative approach for the seismic adjustment and energetic retrofitting of existing buildings



Marianna Merlotti

AA 2018-2019

POLITECNICO DI TORINO

Department of Architecture and Design
Master in Architecture for Sustainable Design

The exoskeleton as an integrative approach for the seismic and energetic retrofitting of existing buildings

Supervisor
Prof. Giuseppe Ferro

Student
Marianna Merlotti

Co-supervisors
PhD. Luciana Restuccia
MSc. Lucrezia Martelli

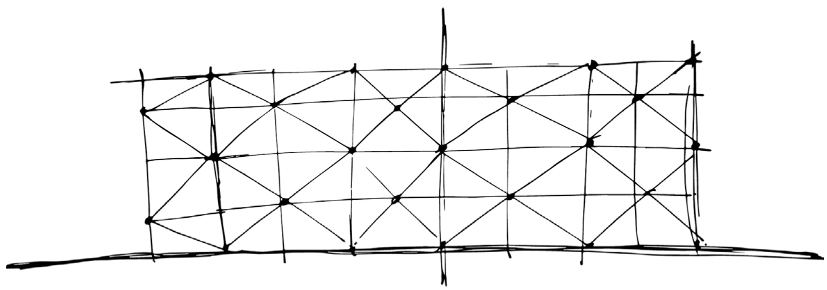
AA 2018/2019

POLITECNICO DI TORINO

1859 1906

UNIVERSIDAD CENTRAL

CARACAS - VENEZUELA



To my parents,
who love me inconditionally and have always
supported all of my dreams,
to my little sisters,
who fill my world with colors,
to my grandpa,
who looks all over us from heaven.

And finally, to all architecture students,
we only have one planet Earth,
it is in our hands to find more sustainable
solutions for the cities and to fix the mistakes of
previous generations.

Acknowledgement

First of all, I would like to thank God and “La Divina Pastora”, for giving me the opportunity and the strenght to come here to Italy to finish my studies.

I’m eternally grateful to my family, who supported me unconditionally over this road, kept me feeling their love and filled me with happiness even with the large distance that separated us this time.

I’m also grateful to my friends and the family we became here, helping each other, having fun, exploring new places and making amazing memories. You have made my trip so incredible.

I especially thank to the professors, particularly to Phd. Lucciana Restuccia, Ing. Lucrezia Martelli and Prof. Ferro, who clarified my mind about the ideas I had for the development of this thesis and guided me all along, so accurately, without any hesitation or delay.

Riassunto

All’indomani della seconda guerra mondiale, la tematica della ricostruzione divenne centrale in tutta Europa e la significativa domanda di costruzioni generò per lo più un’edilizia a basso costo e di bassa qualità. Per tale motivo, il patrimonio immobiliare realizzato tra l’inizio degli anni ’50 e gli anni ‘80 – soprattutto in Italia – risulta vetusto e con grosse carenze dal punto di vista strutturale. Infatti, gli edifici non possiedono i requisiti costruttivi adeguati ad un corretto comportamento struttrale in caso di sisma, sono energivori e la loro immagine architettonica è più che obsoleta.

In Europa, solitamente, la soluzione più comune al problema della vetustà del patrimonio immobiliare è quella legata al concetto di demolizione e ricostruzione. Di contro, in Italia l’approccio metodologico è molto differente, sia per ragioni di tipo culturale che per motivi normativi: risulta quindi necessario trovare una soluzione sostenibile, capace di dare una seconda vita agli edifici esistenti. Inoltre, tralasciando il problema della demolizione da un punto di vista sociale e amministrativo, essa rappresenta una soluzione che ha un impatto notevole sia riguardo la produzione di rifiuti sia riguardo l’immissione in atmosfera di emissioni di $CO2$. Pertanto, il riutilizzo degli edifici risulta una necessità come soluzione maggiormente sensibile alle problematiche economiche, ambientali e sociali dell’abitare contemporaneo.

Lo scopo del presente lavoro di tesi è quello di proporre e valutare una metodologia di intervento chiamata esoscheletro. Tale soluzione progettuale

prevede l'affiancamento ad una struttura esistente di una di tipo autoportante, che permette di conseguire un miglioramento della risposta strutturale sia in campo statico che dinamico. Tale tecnologia, altresì ricollegabile alla funzione di esoscheletro in campo biomedico, sorregge la struttura esistente e si fa carico delle azioni orizzontali durante la fase di sisma.

La tecnologia esoscheletro è stata applicata ad un caso reale, la scuola secondaria di I° grado "Giovanni Ruffini" di Bordighera. In seguito ad analisi dinamiche lineari ed analisi push-over dello stato di fatto, è emerso che la struttura scolastica ad oggi non soddisfa i requisiti di sicurezza strutturale espressi dalla normativa in materia (NTC2018). A ragione di ciò, è stato studiato ed implementato un esoscheletro capace di elongare la vita utile dell'edificio esistente migliorandone le prestazioni nei confronti delle azioni sismiche.

Nell'ottica di una soluzione progettuale integrata, l'esoscheletro è stato ottimizzato anche in funzione dei risvolti tecnologici, energetici ed architettonici che si sono voluti perseguire durante il lavoro di tesi: il risultato è un intero rinnovamento dell'edificio, funzionale sia dal punto di vista strutturale che in tema di efficienza energetica.

L'approccio progettuale dell' esoscheletro risulta quindi una soluzione estremamente interessante, in quanto può essere "confezionata" in base alle esigenze reali coniugando i requisiti di sicurezza strutturale alle funzioni legate ai miglioramenti energetico, tecnologico/prestazionale ed architettonico/urbanistico dell'edificio.

Abstract

In the aftermath of the Second World War, the subject of reconstruction became central throughout Europe and the significant demand for buildings generated mostly low-cost and low-quality structures. For this reason, the real estate constructions between the beginning of the 1950s and the 1980s turned out to be ancient and with great deficiencies from the structural point of view, especially in Italy. In fact, the buildings do not have the adequate construction requirements for a correct structural behavior in case of an earthquake, they are energy-intensive and their architectural image is more than obsolete.

In Europe, the most common solution to the problem of the oldness of the real estate is usually linked to the concept of demolition and reconstruction. On the other hand, in Italy the methodological approach is very different, both for cultural and regulatory reasons: it is therefore necessary to find a sustainable solution, capable of giving a second life to existing buildings. Moreover, leaving aside the problem of demolition from a social and administrative point of view, it represents a solution that has a significant impact both on waste production and release of CO2 emissions into the atmosphere. Therefore, the re-use of buildings is a necessity, as it is a more sensitive solution to the economic, environmental and social problems of contemporary living.

The aim of this thesis is to propose and evaluate an intervention methodology called exoskeleton. This design solution consists of joining self-supporting

structure to an existing one that allows an improvement in the structural response to be achieved both in the static and dynamic fields. This technology, which is also linked to the function of biomedical exoskeletons, supports the existing structure and takes on horizontal actions during the earthquake phase.

Exoskeleton technology was applied to a real case, Giovanni Ruffini's Secondary School located in Bordighera, Italy. Following dynamic linear analyzes and push-over analysis of the current situation, to date it emerged that the school structure to date does not meet the structural safety requirements expressed by the legislation (NTC2018). Because of this, an exoskeleton capable of elongating the service life of the existing building was introduced in order to improve its performance against seismic actions.

In view of an integrated design solution, the exoskeleton has also been optimized according to the technological, energetic and architectural implications that have been pursued during the thesis work: the result is a complete renovation of the building, which is functional both from a structural point of view and in terms of energy efficiency.

Therefore, the design approach of the exoskeleton is an extremely interesting solution, as it can be "packaged" according to real needs by combining structural safety requirements with the functions related to the energetic, technological/performance and architectural/urban improvements of the building.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF GRAPHICS

State of the Problem

1.1. Introduction

In the last years, the interest over the environmental impact that human activities cause has been growing, and with it, the necessity of developing a sustainable lifestyle has become more important worldwide.

Particularly, the building sector has shown in different studies to be the biggest responsible for the CO2 emissions, waste production and energy consumption, along the whole life cycle of each building. In 2012, for example, the construction sector was responsible for the 33% of the total of waste generated that year, followed for the mining activities with 29%, and manufacturer activities with 11%. Noteworthy, the sector also consumes an elevated amount of natural resources, being responsible for the use of 12% of potable water worldwide, 40% of raw materials, 70% of energy and more, for the total of the annual consumes worldwide. [1]

In Europe, after the World War II, as cities were significantly destroyed, there was a huge necessity to construct an elevated number of structures in a short time period, having as consequence buildings with low standards of quality that represent around 40% of the total recent building stock [2]. These buildings were projected to have a life period of around 50 years, and therefore they are obsolete in the present [3]. In addition to this, most of the cities where these constructions were build, were unknowledge to be significantly seismic areas, and the seismic building code was not elaborated yet; therefore, those buildings are not prepared to resist seismic activities, and consequently there is a lack of seismic resilient cities.

The traditional solution, will be to demolish and reconstruct the problematic buildings, but this is not an efficient sustainable option, as more environmental impacts will be generated, caused by the mining and processing of more raw materials, the big amount of waste generated from demolitions, the energy use to construct a new building, and so much more. On the other hand, from the social point of view, inhabitants most be temporarily relocated from the area. Alternatively, many options to solve this issue are case of study in many European countries, obtaining different and interesting results.[4]

The thesis aims to describe one of these solutions and put it in practice in an existing building as case of study, comparing the building's state of preservation and energetic performance with the seismic and energetic performance after the intervention. Therefore, the analysis will allow assessing the feasibility of the project and the possibility to introduce the same approach to solve issues in other buildings.

1.2. State of the problem

In Italy, the seismic classification of the territory started in 1909 by adding cities after the catastrophic events presented, taking a long time to finally classify the entire country. Nowadays, the entire country is considered seismic area, with different levels of hazard given due the geographic position of each site.[5]

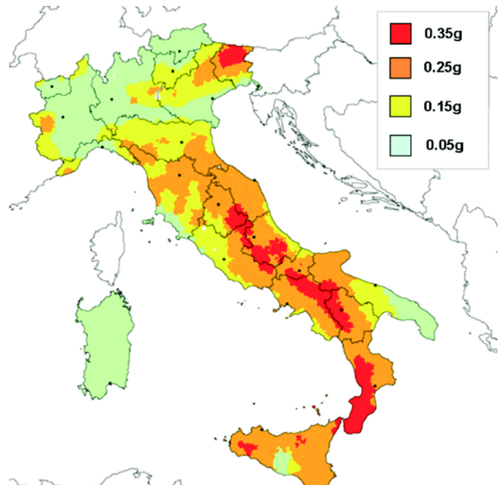


Figure 1. Seismic zone classification in Italy in 2003 [5]

As explained before, the biggest growth of the European building stock, particularly in Italy, took place after the World War II, around the seventies, at a point were seismic regulations were not mandatory, and the seismic classification was not even complete. This brought as a consequence the construction of a large number of reinforced concrete buildings characterized for being "standardized", with no regards of the environmental characteristics of the place they were projected to be, no seismic-resistant structures, poor housing conditions and a low architectural quality in general [4].

The necessity of renovation of the buildings and cities is every day a matter of more importance, not only because of the low quality of the buildings, but also because of their lack of compatibility with the recent seismic codes, their general degradation and obsolescence, as their useful period of time of 50 years has already passed. So, this brings a lack of resilient cities, increasing the possibility of catastrophes and the number of losses in case of hazard [6].

In addition, the environmental impact must be taken in account. Demolition, regardless it is by a disaster or by human planning, represents a significant impact to the environment, as an elevated quantity of waste is generated and the consume of resources to rebuilt the area is quite elevated as well [7]. Another problem, from the social point of view, that represents an additional obstacle to start a renovation is the temporary relocation of the building habitants, it is a serious issue to understand what it means to leave a home, but also to relocate an important number of people [8].

The aspect of time is an important matter, socially and economically speaking. Economically, the expenses for demolition and reconstruction are quite elevated, and it is related also to the time that a new construction would take [9], compared with what a restoration or renovation could significate. In this last option, demolition is only considered for the parts of the building that have no significance or represent a problem to the renovation, decreasing therefore the expenses in this part.

Additionally, the use of an existing structure allows to "use" resources that were already expended, decreasing not only the economic impact but more importantly, the environmental impact and the energetic consumption [10]. Somehow, it is like recycling the structure, upgrading it by solving its current problems and enhancing its performance.

This last possibility could be achieved by the use of an "exoskeleton", an independent structure that is added externally to the building, in a short period of time, designed to attend the current structural issues but also to enhance the building's performance, all without the necessity of relocating the building inhabitants. Therefore, this becomes a feasible option, as it develops in a short period of time, with a lower economic and environmental impact compared to what a new building can significate, allowing also to enhance the image of the city, while respecting in the meantime its heritage.

1.3. Research objectives

Main objective

- Improve seismic resistance and sustainable performance of the Giovanni Ruffini's High School building through the implementation of an exoskeleton.

Specific objectives

- Consider the state of preservation of the building.
- Assess the best proposal for the intervention.
- Increase the building's seismic resistance.
- Enhance the building's energy performance.
- Improve the building's comfort qualities.
- Compare the building's state of preservation with the results after the intervention.

1.4. Research significance

The use of an exoskeleton to solve the problems of existing buildings is a matter of study in many universities around the world, as it allows enhancing the building's performance not only from the structural point of view, but it can be integrated with new technologies to also improve the building's energetic performance, internal comfort and so many other features. It gives also the opportunity to proceed with the construction without any significant intervention in the habitants' life. The construction takes place in a short period of time, engaging the building's issues while increasing its energetic performance, making it a more sustainable and resilient structure.

The study of this kind of solution allows assessing its feasibility, as it enables to understand the possibility of applying it to other buildings, with different structures, while it will surely work efficiently in solving many kinds of issues on each one.

1.5. Scope and limitations

The project aims to corroborate the feasibility of this kind of solution, the use of an exoskeleton, to solve the many structural, degradation and energy performance issues that an existing building may have, by testing the exoskeleton's efficiency over the Giovanni Ruffini's High School building. The analysis should be able to demonstrate how the building is upgraded after the intervention, by comparing the building's state of preservation with the different simulation results, which allow understanding the building's behavior before actually constructing it.

Theoretical framework

2

2.1. Sustainability

The concept appears officially for the first time in 1987 with the Brundtland Report, called “Our Common Future”, were a sustainable development was defined as *“a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”* [11]. Nevertheless, Scientists have been talking about this kind of development for some years before, without giving it a specific term. It is actually in 1798, when scientist Thomas Malthus publishes an essay about the principles of the population, in which he explains his famous “Population Theory”, saying that the population is growing faster than resources [12].

Unfortunately, it is not until 1972 in Stockholm, when governments decide to start taking in account this important matter, and so they meet for a conference of the United Nations about the human action over the environment. It is in this first encounter when finally, the attention is directed over the protection of natural environment. Therefore, this conference is considered the first step for the definition of a sustainable development, and it is here where the bases for the natural environment protection and human development were established.

Consequently, over 10 years later it was published the famous Brundtland report, by the World Commission on Environment and Development, where not only the concept of a sustainable development was established but also the causes of environmental degradation were explained. In this report, it was synthetized the strict relation between ecology, economy and social equity, and possible politic solutions integrating all the three areas were also developed [13].

In this ambit, sustainability refers to the use of the biosphere from the current generations being able to keep its potential to the benefit of the future ones, developing also economic, technologic and social models that are in the capacity of avoiding the impoverishment of the natural resources and the downgrade of the environmental ones.

Moreover, back on the historical track, the next important date is 1992, when another United Nations Conference for the Environment and Development took place in Rio di Janeiro, having as result the “Declaration of Rio on environment and Development” [14], establishing the principles for environmental protection as an integral part of the development process, pressing governments to develop the necessary politics and models to ensure their country environmental responsiveness, care and retrieval. Noteworthy, it is in this declaration where the Agenda 21 takes place, consisting in a group of matters to be engaged worldwide in order to achieve a truthful sustainable development [15].

More recently, in September 2015 this agenda was rechecked and gave birth to the “Sustainable Development Goals”, which should be accomplished worldwide by 2030 [16]. In this occasion, it was clarified the unsustainability of the current development model in all sides of it, such as the economic, social and environmental aspects. The idea was clear, to develop an integrated vision regarding all the development dimensions. To accomplish it, all countries reunited in order to elaborate a model that could be equally capable to carry all countries, no matter of their development status, through the sustainability path.

As result, the series of goals established have a worldwide nature and they are not independent from each other, so they have to be applied integrally. Because of their nature, they take in account the different realities, capacities and levels of development of each country, respecting their national policies and priorities. The targets are divided into 17 points, 5 specifically regarding the natural environment. Synthetically, they are:

1. No poverty
2. Zero hunger
3. Good health and well-being
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth
9. Industry, innovation and infrastructure
10. Reduced inequalities
11. Sustainable cities and communities

12. Responsible consumption and production
13. Climate action
14. Life bellow water
15. Life on the land
16. Peace, justice and strong instructions
17. Partnerships for the goals

[16]

In the Italian context, worldwide regulations has been adopted to be applied inside the country. Since the first reunions, Italy has been aware of the necessity to adapt a more sustainable administration and life style. All the Directives, norms, standards and regulations regarding the sustainability matter are received and validated by the UNI entity, which is the Italian National Unification Body, or "Ente Nazionale Italiano di Unificazione". This organization works in the country since almost 100 years with the aim of elaborating and publicating all the regulations and laws from all the commercial related sectors, such as industrial and tertiary [17].

One of the most influencing regulation is the European Directive 2002/91/CE, which introduces the Energy Performance Certificate as a tool to measure the energetic performance of buildings. Years later the European Directive 2010/31/CE establishes as mandatory the Energy Performance Certificate for all the buildings inside the European Union [18].

More ahead, in 2015, it was establish a standard known as the NZEB standard, and it refers to the construction of Near to Zero Emission Buildings. This regulation establish that from 2019 it is mandatory that all buildings of new construction and renovation projects from the public administration, must be NZEB buildings, while for the rest of the construction sector, the regulation applies from 2021 [19].

However , the "Italian alliance for sustainable development" elaborated a report in 2017, in which they explain that *"despite the progress made in some of the targets for sustainable development in the last years, Italy continues to not being in the conditions of a sustainable development as it is described in the 2030's Agenda, and at least a radical change on its own development model is made, it will not be in place to center neither the proposed targets for 2020, nor does for 2030"* [20].

Anyway, the Italian efforts in order to achieve the worldwide sustainable goals grow every day. The 2017 report is a proof of continuously analysis over the countries performance and it allows to understand the deficiencies and the problems to solve in order to achieve the targets, as it verifies the current situation and achievements. To improve continuously is also part of a sustainable approach.

2.2. Definition of Concepts

In order to have a better understanding of the further explanations and topics, it is necessary to clarify some concepts related to the sustainability context, and which are not only applicable to the construction ambit, but also of relevance for the aim of this thesis.

Life Cycle of a Product:

This concept refers to the whole life of a determinate product, from the obtaining of the raw materials, their production, the fabrication of its components, its use, demission or recycling, as this product consumes energy and non-renewable resources.

In sustainability, a known concept is the "Life Cycle Assessment", and it is not other than the evaluation of the entire environmental impact of a product during its life span. In order to be able to make this kind of evaluation it is necessary to define several aspects for each one of the life faces of a specific product, such as energetic and raw material balances, harmful emissions in water, air and earth, quantity of rubbish generated and the possibility of reuse or recycling. This concept appears consequently to the increasing global awareness about the importance of protecting the environment and how the products are strictly associated with its degradation, and therefore the necessity of taking in account the climate change issues and worldwide biodiversity from a more holistic perspective. This approach allows then to develop methods that help to have a better understanding on the impacts of the products and how to address them in a more sustainable way. [18]

The Life Cycle Assessment or LCA concept and methodological principals are established in the Normative ISO 14040-2006 [21], and it is often use in collaboration with the Normative ISO 15686-2008, which introduces the concept of Life Cycle Cost Analysis [22].

Ecological Footprint:

The concept first appears in 1992, in an academic publication by William Rees. It measures the human demands over the terrestrial ecosystem, this means the quantity of earth biologically productive and marine area needed in order to assist people, their activities and to assimilate the produced waste. In other terms this evaluation allows to estimate the quantity of Earth needed to sustain human life if everyone follows a determined life style. Although the ecological footprint should not surpass the 1,8 global hectare per person annually (GHA), nowadays it is consummated a media of approximately 2,7gha per person. [23-24]

Carbon Footprint:

By definitions is the total amount of emissions generated by a material, product, process, person, event or element. It is expressed in Kilograms of CO2 equivalent, a value that is determine through the Green House Gas Emission Assessment. [25]

Embodied Energy:

The concept makes allusion to the total of all the energy necessary in the production of a certain product, from the mining of the raw materials, transport, elaboration, assemble, installation, disassemble, deconstruction, decomposition and or recycling. It might also include the “Feedstock Energy”, which is the accumulated energy in the material that is not used as fuel and can be liberated whenever the product is burned. This concept is generally useful to determinate the efficiency in the energy saving or producing of a manufacture, it also allows to understand the replacement cost of a building, and how products impact on global warming [26].

Holistic Approach:

In general, the term holistic comes from the idea that *“the whole is more than just the total of its parts, theoretically or in practice”. [27]*

In architecture, the term is expressed as holistic design, which is an approach that understands a project as an interconnected everything that is also part of a larger world. In this matter, the focus is dependent to its context, considering also the aesthetics, the surroundings, environmental characteristics, sustainability possibilities, technologies and spirituality; this last one refers to cultural and social aspects [8].

Recycling:

Recycle is a process of recuperation and transformation, weather is chemical of physical, of any waste, which allows producing new materials or products [28]. This process can be to of two types, the first, allows to upgrade the quality of the material to be recycled or to transformed into a material of more value, in which case is a upcycling of a product; while the second type, the downcycling, is the contrary result, the material to dismiss losses quality and/ or value during the recycling process [29].

2.3. The exoskeleton

The word has its origins from the Greek ἐξω, éxō "outer" and σκελετός, skeletós "skeleton", and it refers to the external layer that protects some animal's body, like insects, that can be compared with the internal skeleton that supports many kinds of living beings. In architecture, the concept "skeleton" is often use to make reference to the structure that supports an entire system, for that reason the distinction "exo-" makes allusion to the exterior system that supports a building[7].

To begin with, the exoskeleton is a modern concept and construction system, often built in steel or reinforced concrete. This new way of constructing allows to achieve new forms, stability and height, it allows to imagine a whole new architecture. Its first appearance was between 1896 and 1919 in Russia, by Vladimir Shukhov, who tried to elaborate a structural system to serve a civil engineering function without necessarily being "pure architecture". Therefore, this is one of the examples when architecture and engineering cross their path, working together to achieve a better form [30].

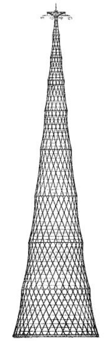


Figure 2. Vladimir Shukhov Tower [30]

In this first appearance, the system was recognized as "Diagrid", which is no other than the combination of the words "diagonal" and "grid". This system works through the use of triangulation to allow its structural integrity, obtaining a structural system that is single-thickness in nature [30].

It is important to understand that the single diagonal grid, which is often the most evident part in the aesthetics of the diagrid buildings is unstable by itself; and therefore it has a need for triangulation in order to obtain adequacy in the assembly. Consequently, horizontal bracings may be necessary to act in tension or in compression. These bracings are mostly constructed by the edge of the beam in the floor structure, framing to complete a triangle.

One of the critical or most important points in the scheme are the nodes, which is where the main structural intersection follows. They are fabricated for each individual point of connection between the elements of the structure, making it important to minimize their variations, occurrence and as a result simplify each joint.

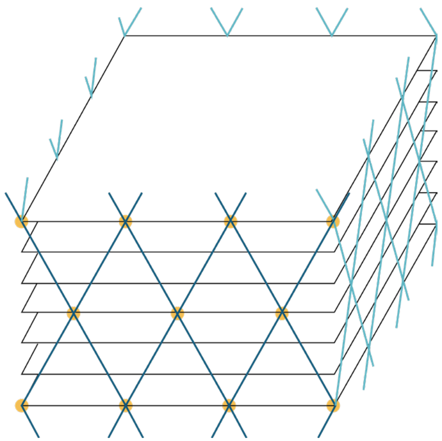


Figure 3. Diagrid Structure Scheme

The development of this system comes from the knowledge that vertical columns carry gravity loads and are, therefore, incapable of lateral stability by themselves. The diagrid instead, has the ability to combine the resistance to gravity and lateral loads into a triangulated scheme that banes the necessity for vertical columns and that is why is often used in the perimeter of the buildings.

Once used as a perimeter structure, the diagrid scheme allows constructing, not only free column and large internal spaces, but also a huge range of forms, from regular orthogonal buildings to ones with multiple curvatures and/or undefined geometric forms. The system can also be related to other structural methods like space frames, space trusses or geodesic structures, as it is proven that the diagrid and its developments is no other than a consequence from the analysis of these methods [30].

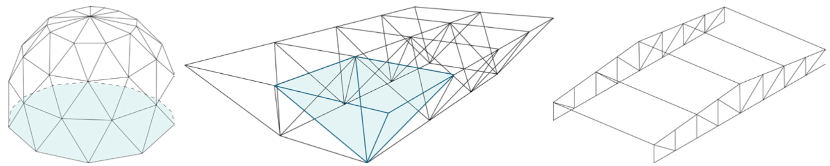


Figure 4. Geodesic, space frames and space trusses structures schemes, respectively

The innovative and intriguing part of this construction method is that a basic typology of design does not exist, differently from the Modernist construction methods. As a result, the Contemporary buildings are often unique, pushing the engineering technology to accomplish the architectural ambitions, working more closely every day. The remarkable difference between each constructed structure, in every element that composed it, gives the idea of the continue research for the optimization of the structures, and the exploration of the new form that is characterizing the current architecture. The diagrid buildings constructed until now come from the simpler design and low height buildings, to new shapes, configurations and taller buildings every time [30].

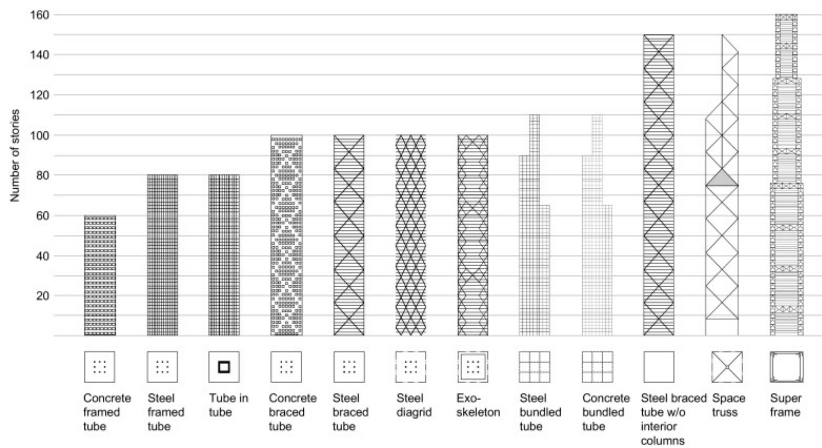


Figure 5. Exoskeleton existent configurations [31]

2.4. A different use for the exoskeleton

The exoskeleton is a kind of structure that not only works for new assemblies, but also to fixing, supporting and enhancing existing buildings, so as to give them another chance to continue their useful period of life. It also allows proposing a more sustainable way for solving the urbanism problems that came as a result from the fast and unconscious building after the WWII. This brought as consequence the construction of many seismic unresisting buildings, as they were constructed before the nowadays-seismic regulations were established; but also high energetic demand buildings, as the environmental issues that occur nowadays were unknown at the time.

As a result, the buildings can be renovated, or in other terms recycled, encouraging design principles such as resilience, safety and sustainability. At the same time, the new project takes advantage of a construction that is already finished, avoiding the wastes and energy consumption from demolition, and the resources consumption that a new building could mean, upcycling then an existing obsolete building, to a seismic and sustainable project, even enhancing its general aesthetic; in conclusion a whole "new" project is developed [32].

The exoskeleton then, allows upgrading the seismic characteristics of an obsolete building, by adopting specific or global strengthening; the choice will depend on the current rigidity of the building, the critical points and the external available space for construction. Accordingly, as said from S. Labò, C. Passoni, A. Marini, A. Belleri, G. Camata, P. Riva, E. Spacone, *"the seismic resistant structure can be obtained by reinforcing the existing concrete walls with high performance jackets, or by transforming a single bay of the frame into a seismic resistant shear walls by strengthening the infill wall"* [8].

The use of this kind of system requires to work from the outside, and allows attaining the structural targets by accompanying the enclosing exoskeleton with shear walls, this way developing and exploiting in the best way the behavior of the new façade. This means that, by adding a new structure, depending of the project, new uses or areas can be adapted on it, expanding at the same time the structure itself if needed [10].

Furthermore, there is the possibility of adding new technologies to this new layer of the building, and here is where the energy performance of the building can be enhance, giving the possibility to the edifice to be sustainable, for a long period of time [33]. An interesting aspect with the implementation of this strategy is that, by working from the outside, the installation of the new structure does not interrupt the normal building's operations, therefore avoiding the issues that relocating inhabitants and demolitions might mean [32]. The fact that exoskeletons need a smaller intervention and the construction activities are considerably shorter compared with the time that a new construction could take; its use is consider to be in harmony with the ideologies of sustainability and eco-efficiency [8].

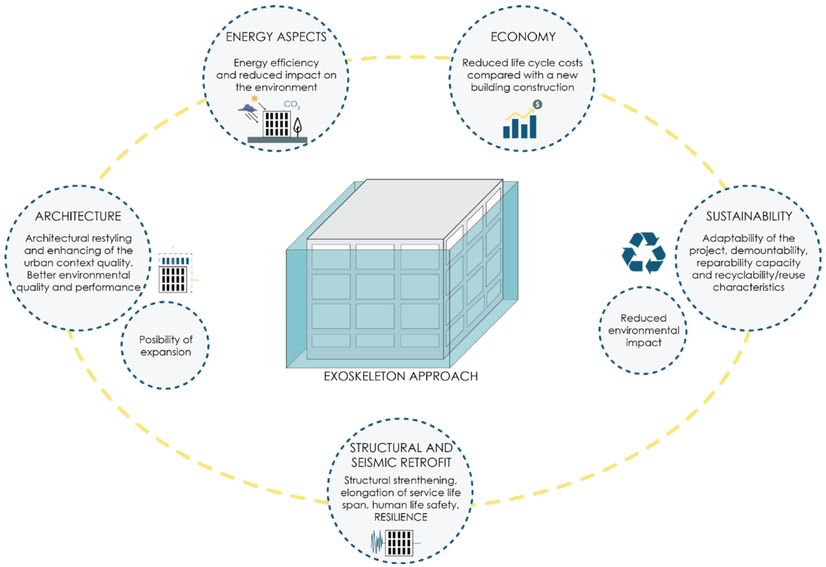


Figure 6. Main goals in the use of the exoskeleton approach [32]

On the other hand, in order to implement an exoskeleton to a building, the most important aspect is to count with enough external free areas near the facades, so that the installation of the exoskeleton foundations and other structural elements is possible [10].

Generally speaking, an exoskeleton will not only allow to fix structural issues of a building, but also to change its image, more according to the current architectural styles, and to update the building to the current worldwide needs, as cities must be more environmentally friendly, achieving a more sustainable urban life style.

2.5. The concept of the double skin

As explained before, buildings constructed after the WWII not only present structural deficiencies from the seismic point of view, but they are also characterize by an elevated energetic demand, low comfort quality, and in general, a bad environmental performance. Already adding a new structure to fix the structural issues of the building, the possibility of adding new systems to enhance the energetic and environmental performance of the building, as much as the renovation of the building image, is quite relevant. At this point, is where the concept of a “Double Skin” or “Second Skin” appears [34].

This concept refers to the new façade that is added to the building, a separated technological element that is attached or linked to the existent structure, while remaining structurally independent. As consequence, it becomes an integrative approach from the sustainable, architectonic and structural points of view. This new element then is conceived to enhance the energetic performance of the building, its aesthetic and its structural issues [35].

First of all, the element is developed as an exoskeleton, as it has been conceptualized in the precedent paragraphs, to solve all the static and resistance deficiencies of the building. As an advantage, this new structure does not get involved neither with the existing structure nor its foundations, therefore the assembly process does not takes much time, no matter what the materials or type of element are chosen for the construction. This structure is also thought to be easily adapted over time to new requirements of technologies, as much as possible future adaptations according to the needs of the inhabitants, always under the principals of low environmental impacts and minimum costs. Each project is specifically design for the building needs, giving the necessity to carry on with a severe previous analysis of the building, before starting the project [34].

An interesting aspect is that the new skin either can be attached to the existing building or separated from it, enabling the possibility of expansion of the building, by adding new spaces, however they are open spaces, or enclose areas with new uses. In the same way, this kind of intervention allows to add new floors to the edifice, due to the structural enhancing of the structure [32].

2.6. Feasibility of the approach

As mentioned in the previous paragraphs, the exoskeleton intervention is a type of construction that is carried on from outside of the building, with a minimal intervention to the original structure. Adding to this aspect the integration of structural elements with sustainable features and a new architectural façade, while at the same time respecting urban planning regulation; it represents a remarkable design effort, as it is a challenge from every point of view, including the social or cultural approach.

If this type of intervention is analyzed from a Life Cycle approach, is easier to understand its feasibility. First of all, there is an existing volume, with a considerable value for embodied energy, which translates into a critical amount of resources that are already expended. The common approach into solving and existing but obsolete structure that has surely accomplished its service life span; is to demolish it. Once this building is demolished, there is an alarming amount of rubbish generated, which often remains into desolate areas, where they are not transformed or recycled. Noteworthy, not all of the remaining materials can be recycled, and if so, a large amount of energy is needed in order to carry on with the recycling process, and even with that, materials like concrete, lose mechanical properties, becoming a lower quality material. Consequently, a new building is constructed in the place of the demolition, adding new resources expenditure, more energy requirements, and so on; even if the new structure is a near to zero energy building, there is an important energy expenditure in order to construct it, in other words, a significant amount of resources is still needed to accomplish the project [32].

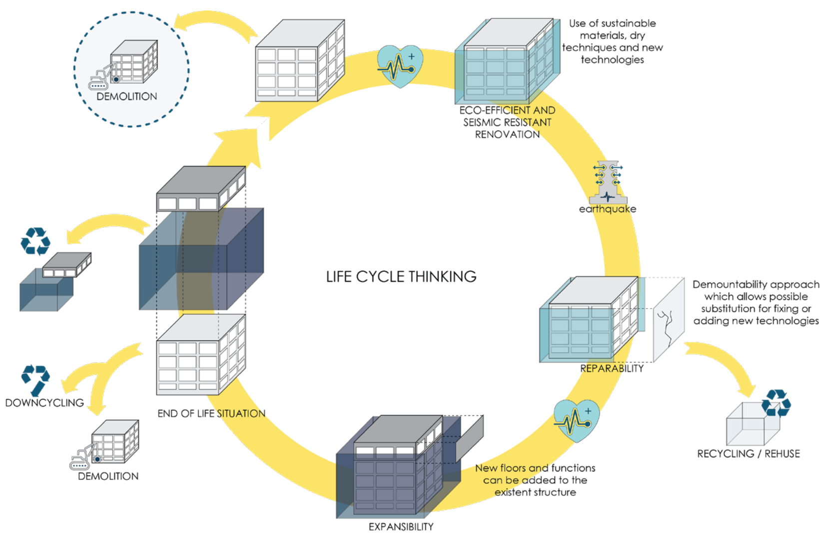


Figure 7. Life cycle thinking scheme with the use of an exoskeleton [32]

A more sustainable alternative, therefore, is to fix the existing building. The structure is analyzed, critical issues are identify and a new project is proposed. Even if the project is obviously going to need materials, energy and other resources to achieve its elaboration, the amount is significantly lower compared to a demolition plus new project building. New technologies can also be added to enhance the building energetic performance, even to the point of turning it into a Near Zero Energy Building. Another advantage of this approach, also explained in previous parts of the chapter, is the fact of elaborating the structure with the possibility to be demountable, modified and improved over time, elongating even more the service life of the building, are damaged parts ca be easily removed and added technologies can be also substituted in the future. New functions, areas and floors can also be added to the original project, facilitating also a method to cover the intervention costs[32].

At the very end of the service life of the building, when there is no other solution than to demolish it, a good design of the exoskeleton should allow the complete demounting of it, allowing a total recycle or reuse of the elements. This is an essential aspect to ensure sustainability, as it allows designing nearly zero waste constructions; minimizing costs and establishing more near zero energy buildings.

2.7. Pros&Cons in the use of the exoskeleton

Advantages

- Elongates the service life span of a building.
- Allows fixing almost any structural deficiency present in the building.
- Improves the seismic resilience at a district level.
- Reduces the environmental impact related to the seismic risk.
- Gives the possibility to improve the energetic performance.

Disadvantages

- It is mandatory to count with enough free space in the surrounding of the building, in order to be capable to add the new structure and its foundations.
- It is a bigger design challenge compare to a building of new construction.
- By operating from the outside there is a major effort in the evaluation of the capacity of the existing structure, and the way the new structure affects it.

2.8. Existent technologies for energy efficiency

The energy efficiency field, as any other technological field, is not only in constant update but also in constant innovation. The goal is always the same, to elaborate buildings that are energetically more efficient every day, and to develop technologies that allow enhancing the existing ones, while maintaining the aesthetic of buildings and cities.

Nowadays in the Italian context, the existent technologies that are capable of optimizing the energy performance of the buildings can be briefly categorized in the following way [36]:

- Technologies for the reduction of the heating and cooling demand: This category includes all the types of interventions, which involve the building fabric, such as the envelopes insulation, windows retrofit, surface coating, cool roofs, increased air tightness and all kinds of bioclimatic technologies that take advantage of the natural resources and climatic conditions of the area, like for example natural illumination and ventilation, evaporative cooling and so on.

- Technologies for the improvement of the HVAC equipment (Heating, Ventilation and Air Conditioning)
- Installation of RES technologies: RES systems consist in all the technologies that transform natural resources such as wind, water and sun into renewable energy, therefore, this category include all the voices of thermal collectors, photovoltaic panels, hybrid photovoltaic and thermal panels, wind turbines, and so on.
- New technological approaches: makes reference innovative approaches, such as ventilated facades, applying the double skin façade approach or hybrid façades; solar shading devices, passive solar energy systems like solar green houses and green walls and roofs, which allows natural cooling, humidification, oxygen generation, sound isolation and natural air purification.

3 Methodology of analysis

3

3.1. Methodology of analysis

In order to verify the building's state of preservation from the structural behavior and environmental performance, it was necessary to implement the use of different softwares, as some programs allow to calculate more effectively each feature of the building.

The idea was to aid the design process be able to test different solutions along the process, in order to achieve the best result thanks to accurate calculations. Therefore the aim is to compare the building's state of preservation results, with the results after the intervention, how the building changes not only from a structural point of view, but also from its environmental performance.

As a result, the decision was to use the software CDS Win for the structural analysis and the software Design Builder for the environmental assessment of the building. Both programs are quite innovative, as they are relatively new and have a friendly interface in which the user can easily work. Each program also allows to elaborate detailed models, regarding structural elements, materials, buildings characteristics, activities, and so on, giving the program all the aspects of the building needed to provide accurate and detailed results, based also in the current construction regulations.

3.2. CDS WIN

The CDSWin [37] is a structural calculation software that allows the analysis of any kind of structure using the "Finite Element Method" (e.m.m) techniques. The program allows to model and calculate precise special of plane structure with one and two-dimensional elements, such as beams, pillars, partitions, plates, different types of plinths, and so on. The input of the software consist of a precisely programmed and equipped structural CAD with sophisticated features of direct pointing to video of the structural elements, which permit a fast entry of the structure and an easy graphic review of the given informations.

The software is capable of rendering the structure, create different animations according to the building's behavior and to export and import structural models in .dxf format. It is also dotted with two modalities for the graphic input, which can be used simultaneously in the same project, allowing the user to select the easiest data entry phase to model each part of the structure. The first modality is aimed for the modelling of constructions in reinforce concrete, while the second one allows to develop structures with a more complex geometries, such as pylons, special trusses, and so on.

The modelling process

Once on the input, the first step is to insert series of reference points in plan, the fixed wires, which will allow to place the main vertical alignments of the structure. As a result, the pillars and/or other structural elements will respect the position of the fixed wires, and will acquire the physical characteristics indicated by the user. The program counts with a large library of structural elements in order to ease the work of the user, which can be individually modified, or even other elements can be created, allowing to create a precise model. For that reason, the elements like pillars, beams, and so on, can have any kind of section. It is important to enhance that all the sections will be ahead verified by the software in the subsequent calculation phase, with a rigorous analysis of the straight/deflected bending.

Once pillars are completed, under each of them it is possible to place the foundation plinths, from direct ones to piles. Ahead, they will be calculated and designed in collaboration with the program, which automatically creates a static scheme that provides the elastic constraints in correspondence of each plinth, properly schematizing the foundation-structure interaction.

For the beams instead, the program allows to offset the ends of the elements according to the fixed reference wires, which permit to manage particular situations. Moreover, the beams can be inclined, such in horizontal as in vertical, consenting to establish different kinds of arrangements.

To be able elaborate different floors, and work on them separately, it is necessary to insert the various quotes of the building. For easier modelling, equal floors can be fully duplicated.

Finally, it is possible to define two-dimensional elements, such in horizontal as in vertical, creating elements like slabs and their direction and loads, retaining walls, bracing shelves, and so on. Through the implementation of slabs it is also possible to create pitched roofs, by inclining the slabs; and foundation slabs. The input of the loads is quite simple, the information requested simply tends to define the beams or partitions on which the floors are warped, where the balconies are arranged and where there are any walls, however they are perimeter or internal. The option is also given to the user to openly define the value of the load acting on the elements in question.

It is quite interesting how the program automatically drags the elements if the fixed wires of a node are modified in quota or position, this is a procedure that easily allows to create complex shapes, that will be automatically meshed by the program. Another useful feature is the possibility to determine different “seismic slabs” in a same quote, helping in the definition of independent towers of structural parts of the building, like an added structure for example.

The analysis process

The CDS Win’s module for the verification of all the structural elements is adapt to the current seismic standards. As explained before, the structure may consist of any kind of material, structures with bracings, pitched roofs, inclined rods, elevation and foundation plates (slabs), vertical or inclined baffles, also perforated, with slab and/or plate-plate behavior, axisymmetric, are analyzed by the program without issues.

CDS Win makes possible to carry out the design of isolated structures at the base of constructions where devices are foreseen, known as seismic isolators, to be placed between the foundation and the marked building capable of preventing the entry of seismic excitation. The plinths, both direct and on piles, are automatically schematized in the model with equivalent stiffnesses, thus evaluating the foundation-structure interaction.

CDsWin considerate the shear deformability of both shells and rods and the presence of any infinitely rigid initial and final traits. In particular the offsets supplied in input for the positioning of beams, shells and pillars are taken into account automatically by the calculation model, following a precise correspondence between the graphic model of the structure and the analyzed static scheme. Seismic analysis provides the possibility of choosing between:

- Linear static.
- Dynamics.
- Non-linear static “push-over”.

It is possible to perform seismic calculations with or without a rigid deck. The seismic calculation of a structure with rigid decks is automatically enveloped with the thermal resolution of the same without rigid decks.

The Push-Over analysis

Is a kind of analysis that works over increase, taking into consideration the collapse of several structural elements as they happen, evaluating at the same time the necessary redistribution of the shares through the general discharge technique. All the resistance values, types of stress and the rotational capacity of the hinges are calculated in order to the current seismic regulations and the Eurocodes.

It is important to remark that for steel structural elements, the non-linear analysis depends only on the geometry of the sections and on the mechanical features of the material, while for the verification of the structures in reinforced concrete it is necessary to know the armor. It is hence a re-verification in the case of new buildings, based on the design reinforcement, whereas for existing constructions it is required to define the reinforcements in the sections with the input phases.

The safety verifications in this type of analysis are acquired by comparing the Capacity Curve, which describes how the total resistant cut at the base differs according to the shift of the center of gravity of the last floor, with the quake demand expressed in terms of displacement. The verifications will be carried out, establishing on the curve the several levels of performance in terms of building displacement capacity, and corroborating that the displacement demand due to the earthquake expected on the site for that level of performance is lower. CDS Win also reports the PGA limit values for the various performance levels required by the norm.

The verification results

Through the elaboration of the project it is possible to distinguish certain parameters, such as the materials characteristics, measures, torsional stiffness percentages and so on, which will determine the final reinforcement of the structural elements. In this manner, the program determines the characteristics of stress and brings on all the resistance verifications for the rods.

For seismic walls, the current standards requires verifications to be carried out at the S.L.U., as explained in the NTC 2018 regulation; guaranteeing ductile collapse modes, and are carried out rigorously with the software. From the solution to the finished elements, the characteristics of the stress acting on the section and the associated regulatory verifications are in fact defined. In particular, the various methods of shear failure and compound bending will be verified.

The results

The software has a series of processes to evaluate and verify the calculation results, which permit to rapidly identify any particular issue. Also, the program generates an output that allows to display deformations and stress regime of each structural element.

The interface gives the possibility to choose between static, seismic and thermal deformations of the structure, which are related to the various conditions and loads combinations. It also allows to choose between elastic deformations and kinematic ones, to activate de deformation colormap, allowing to visually identify the displacement values of the structure, based in a color system. It is also available the diagram that contains the characteristics of the different stress, which also generates another colormap to visually identify the values of this stresses base on the coloring, identifying any issue in the structure in the easiest way. Also through color diagrams there is the possibility to visualize the relative displacements between the top and the base of the pillars, to analize the limits imposed by the standard on this size.

Another interesting output is the animation mode, which takes advantage of the graphic acceleration of the hardware to illustrate though the movement of the structure, its deformation.

A quite important graphic possibility is the "verification coloring", which allows the color scale display of all the results from the verification for rod elements (reinforced concrete and steel) and shell elements; some quantities that can be displayed are for example for auctions in AC are total area irons, needle density, minimum bracket pitch, pressure on the ground, unverified auctions and so on. With the "auction results" procedure it is possible to select any auction and directly visualize the results of the bending, cutting, torsion, and other verifications [37].

3.3. Design Builder

Design builder [38] is a software that provides a large variety of environmental performance statistics of a particular building, which is 3d modelled inside the program. It is aimed to aid in the design criteria choices to provide high quality, sustainable and comfortable buildings. It also helps with the building regulations, to minimize costs, optimize the energetic performance and reduce the environmental impact.

The calculation results include data such as energy consumption, carbon emissions, comfort conditions, temperatures, cooling and heating components, and so on.

Therefore the program is often use to calculate the impact of several design option about the buildings energy consumption, allowing to easily compare the results of each option, as the program enables to generate a wide range of reports, graphics and outputs. The program also generates interesting simulations, such as thermal situations, natural ventilation, prediction of daylight distribution and solar shading. The program also allows to elaborate a detailed simulation of the cooling and heating design, even estimating the impact of the air distribution supply over the temperature and velocity distribution in a room. It is also possible to run the AEHRAE and LEED energy models, and to elaborate the economic analysis based on construction costs, utility costs, life cycle costs and life cycle analysis.

More importantly, the program interface allows to create complex models in a small amount of time and effort, enabling to insert all the buildings characteristics, from the materials of the structure to the type of glazing and frames, to the activity that is developed in each area of the building, including the amount of people and the type of equipment located there. For an easier modelling, it allows to import an existing BIM or CAD drawing, and gives the opportunity to modify and optimize the building at any stage of the process.

The program also works in collaboration with EnergyPlus, as a dynamic simulation engine, in order to obtain precise performance data. This simulator is used for modeling energy consumption and water use in buildings, between its features it is quite remarkable how the program is capable of generate integrated and simultaneous solutions regarding the thermal zone conditions and HAVAC system response and heat balance that affects the surface temperatures, influencing the comfort characteristics of the building.

The calculations also take into account how each zone of the building influence into one and other, taking into account the air movement between each one. An important part of the outputs of the program is to give hourly, sub-hourly and different data results, based on the environmental characteristics of the different possible locations of the project, which is why the program accounts with a wide range of environmental and regulation data from around the world, that are regularly updated.

The modelling process

As said before, the program interface allows an easy modelling phase, as the 3d model that is generated in the program is quite simple. The software works with “building blocks”, which is no other than a 3d figure, regular or not, that define all the external walls of the building. It is not necessary to draw the walls thickness, structural characteristics, pillars, beams and others, once the building block is draw this characteristics are specified in the “construction” options of the model, making it this way pretty easy to change the building’s materials and characteristics without the necessity of restarting the 3d model; this feature also allows to compare how the building performs with the use of different kinds of materials.

After the building block is define, windows can be placed automatically by indicating measurements and separations in the glazing options, or they can be individually drawn. Glazing options, including frames, insulations and double or triple glazing are also possible to indicate to the program, even the quantity and schedule in which the windows are open during the day.

For internal divisions of the building it is necessary to divide the building into zones. This zones also give the possibility to indicate each one the kind of activity that is developed inside, the equipment, the hours of use, amount of people inside, type of heating and/or cooling systems, and so on.

It is also possible to add more complex elements, such are pitched roofs, domes, balconies, and so on, with the different features of the program, indicating, as always, their physical and mechanical characteristics.

The visualization

The program also has the feature to elaborate renders and movie renders, allowing to demonstrate the solar shading of the building, at different times and months of the year. The materials and aesthetics of the render can be easily modify according to the construction material features indicated in the modelling phase, and can be modified at any phase of the project.

The simulation

Before running the simulation, it is important to select the different outputs required. Characteristics like natural ventilation, cooling and heating systems must be checked or unchecked according to the project's individualities. As explained before, the program allows to calculate the environmental and performance aspects of the building, such as suface heat transfer, environmental, internal gains, solar gains, energy requirements and performance, temperature distribution, ventilation, comfort, Co2 production, carbon and embodied energy.

It is possible to choose the geographic location of the building, in order to obtain precise results, and also to select the period for the analysis, from 1 day to a whole year, and the amount of data to show per day, such as the results per hour, sub-hour, day, and so on. This is an useful feature to adapt according to the scope of the analysis.

The outputs also can be visualized as graphics, grid or tables, and can be exported to be used in other programs like Microsoft excel, so that the results for different building solutions can be compared [38].

State of preservation of the Giovanni Ruffini's High School

4

4.1. General aspects of the building

The building is an isolated construction located in Via Pelloux, 32 in the city of Bordighera (IM) and is possible to access the school from Via Napoli, in which the principal entrance is located [39].

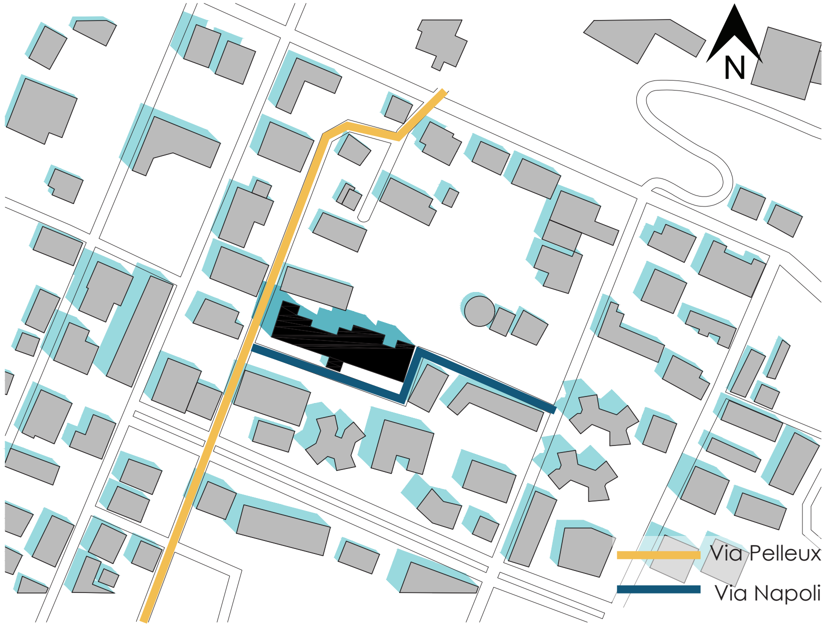


Figure 8. Giovanni Ruffini's location plan

Constructed around 1950 in reinforce concrete, as a high school, the building has kept its original use until nowadays, without big modifications, except for the last one in 2015 in which an additonal portion was constructed. The area is approximately 3000m2, with a construction area of around 1250 m2. The building consists of a basement, a rise floor, first, second floor and a non-use attic.

The basement area is principally used for the experimental laboratories, including a science laboratory, science classroom, kitchen laboratory, and so on. The rest of the floors are dedicated to other classrooms, such as music room, multimedia, computer lab and so on; areas such as archives, teacher's rooms, secretary and director's office are also located in the upper floors. Every floor is furnished with independent services for boys, girls and personal [39]. The school currently hosts 250 students and 45 professionals [40].

Figure 9. Giovanni Ruffini's High School [39]

4.2. Original plans of the building

The original plans were proporcioned by "Studio Techne Associato Q.Q.S.", and included:

- Foundations plan
- Structural and architectonic plan of the basement
- Structural and architectonic plan of the ground floor
- Structural and architectonic plan of the first floor
- Structural and architectonic plan of the second floor
- North facade
- South facade
- East facade
- West facade

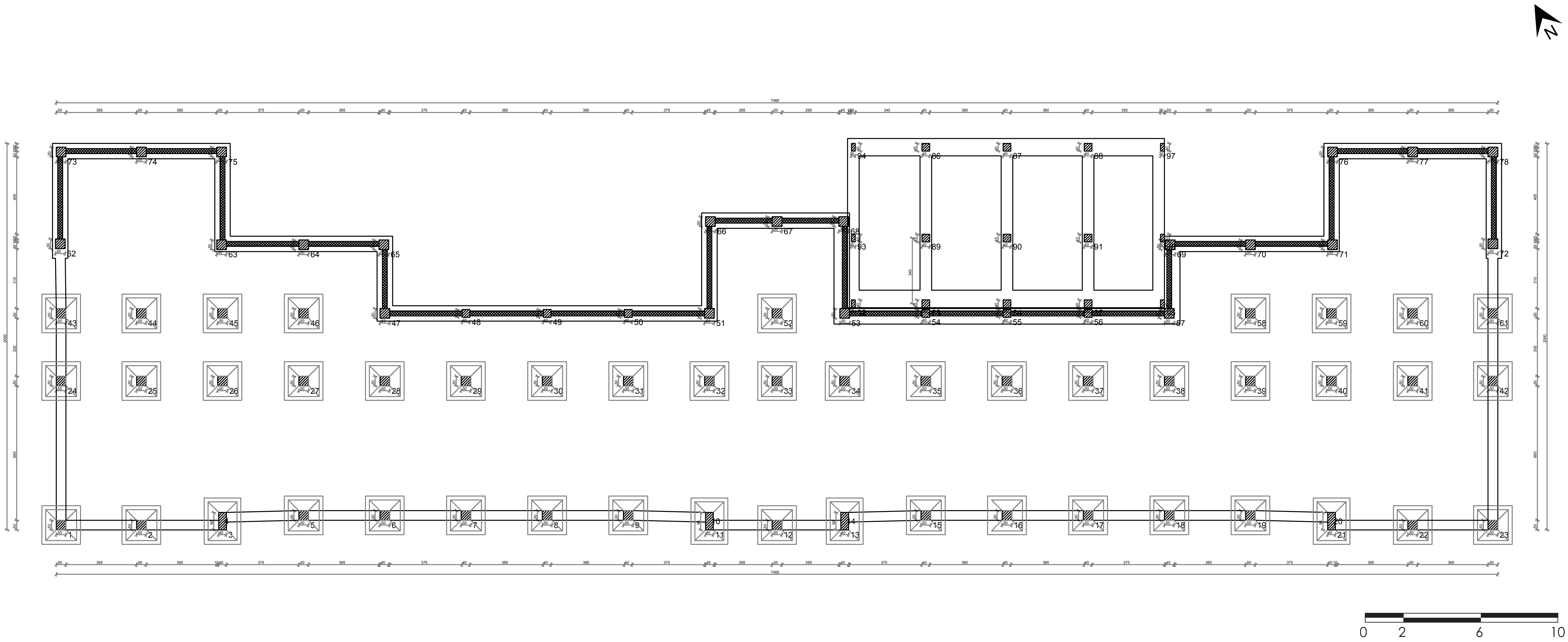


Figure 10. Foundation's Plan
Quote +/- 0,00 m | Scale 1:200

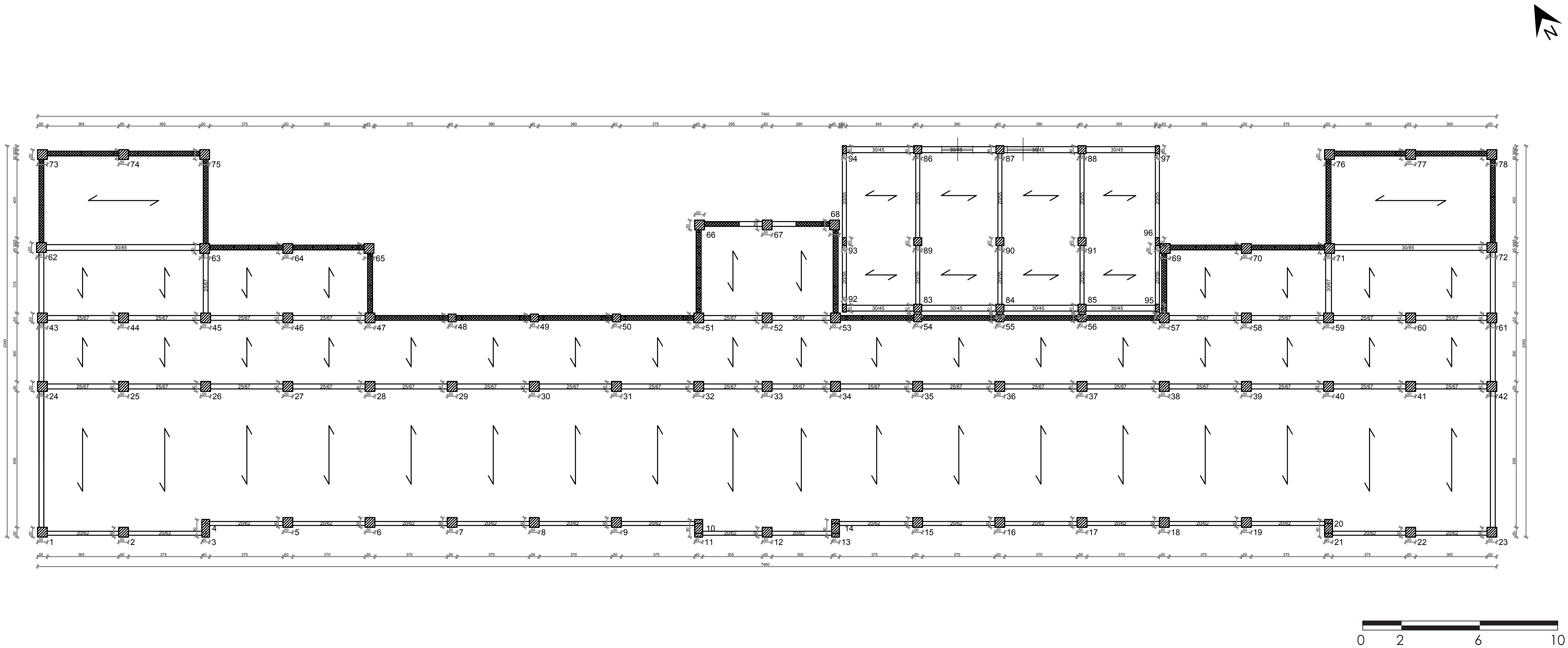


Figure 11. Basement Structural Floor Plan
Quote + 3,60 m | Scale 1:200

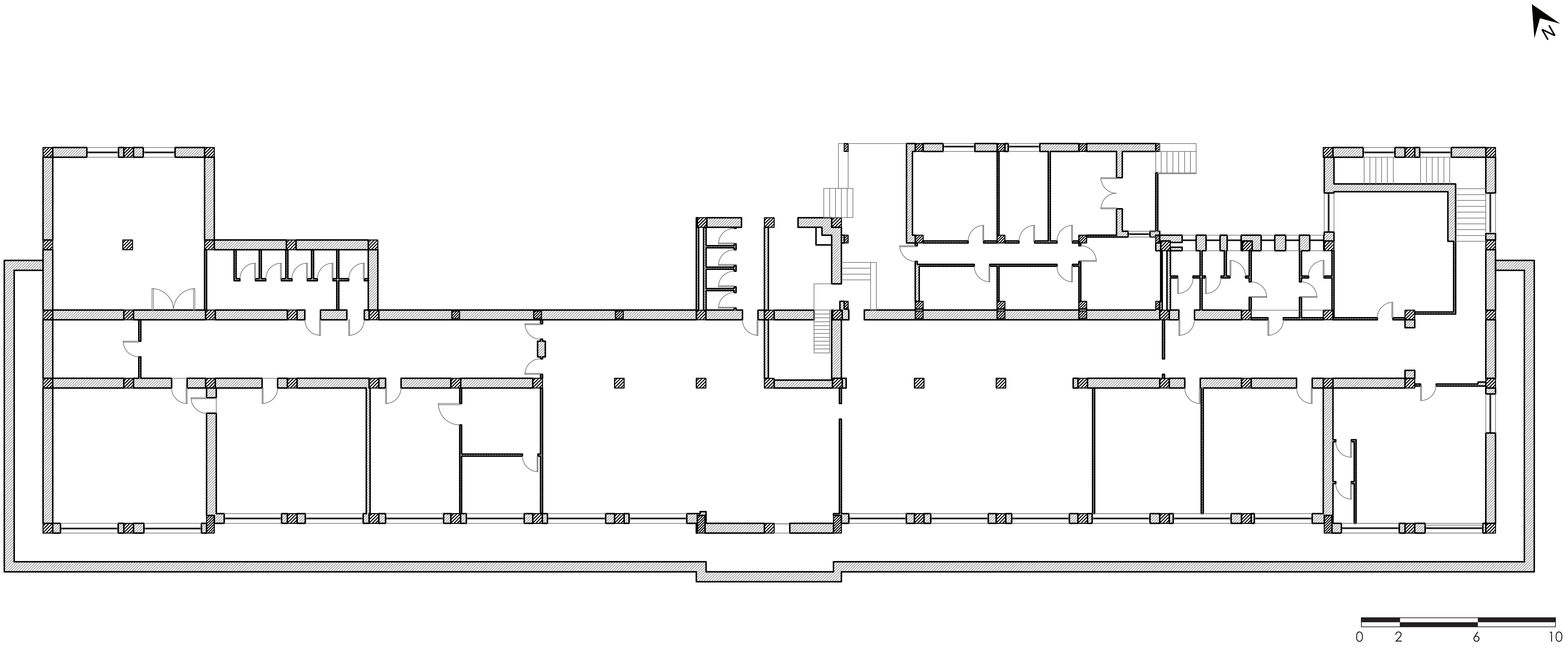


Figure 12. Basement Architectural Floor Plan
Quote + 3,60 m | Scale 1:200

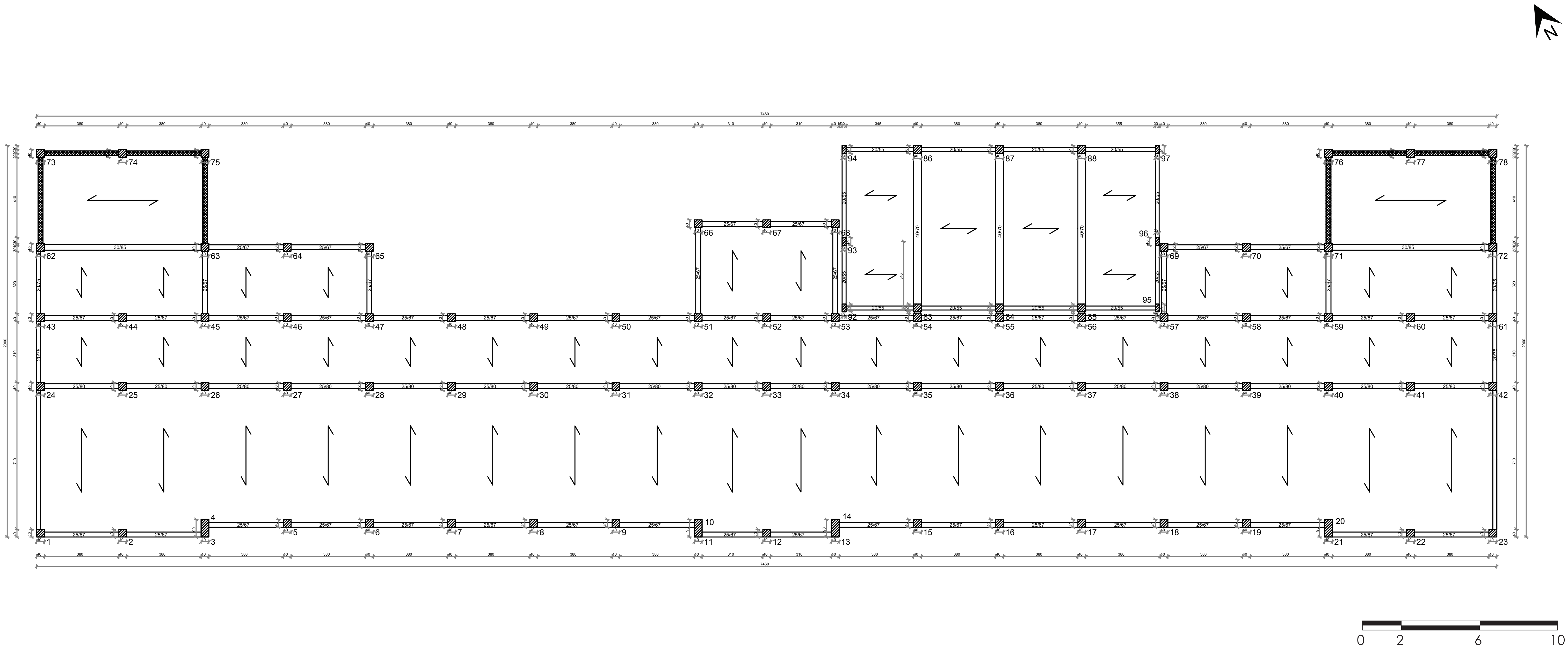


Figure 13. Mezzanine Floor Structural Plan
Quote + 7,43 m | Scale 1:200

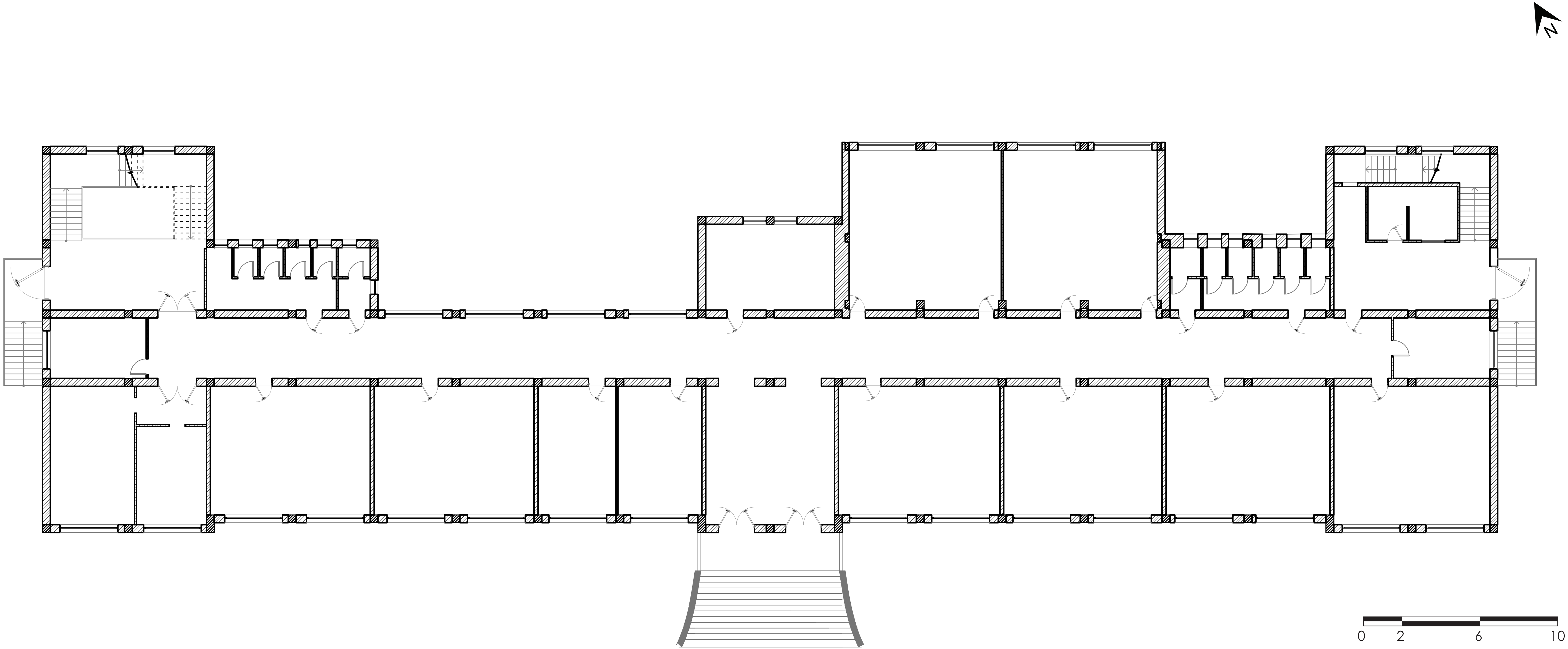


Figure 14. Mezzanine Floor Architectural Plan
Quote +7,43 m | Scale 1:200

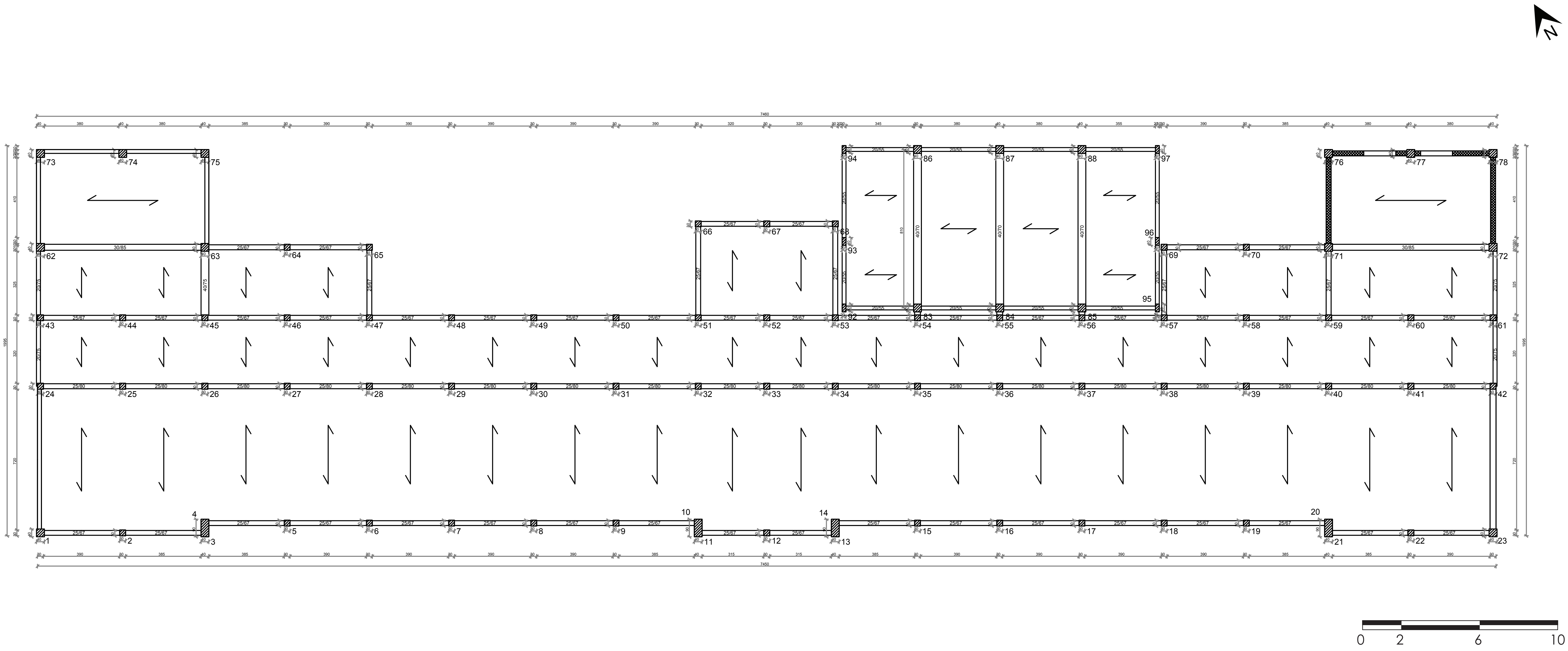


Figure 15. First Floor Structural Plan
Quote + 11,25 m | Scale 1:200

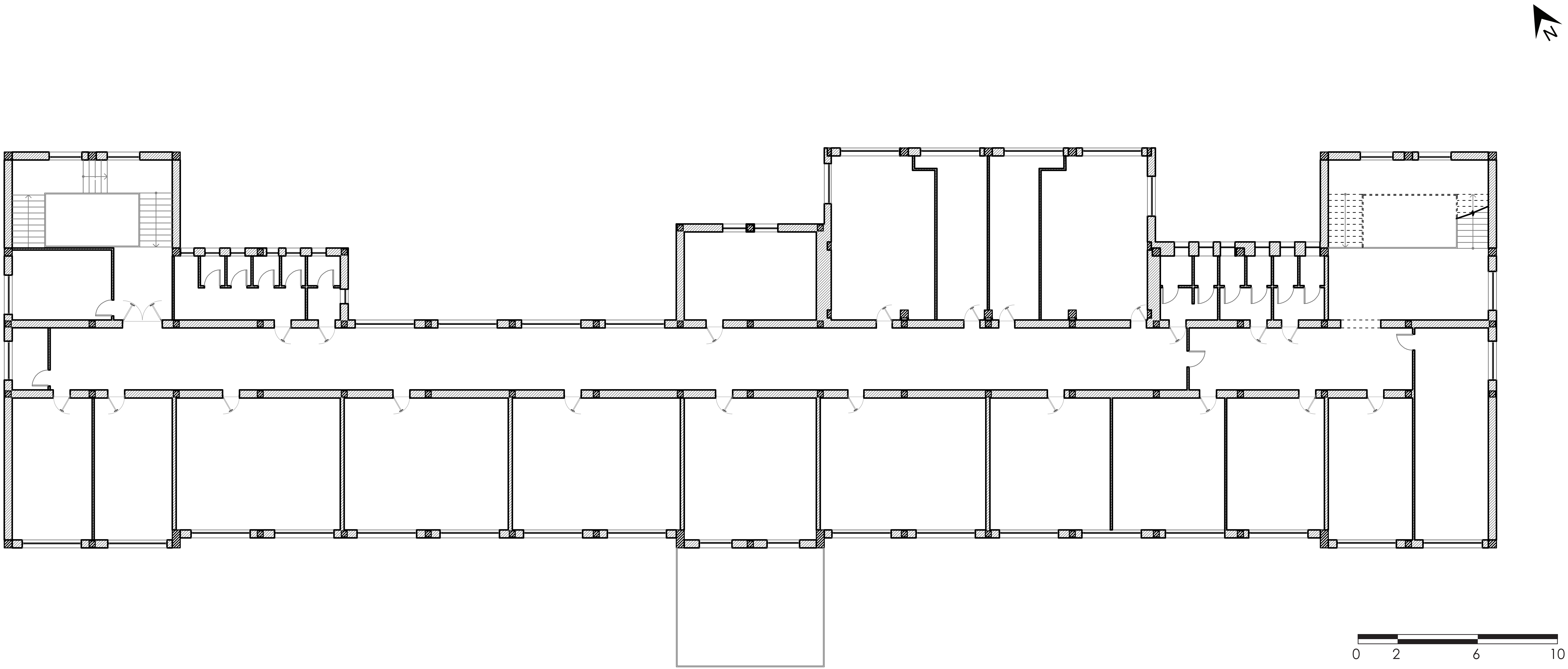


Figure 16. First Floor Architectural Plan
Quote + 11,25 m | Scale 1:200

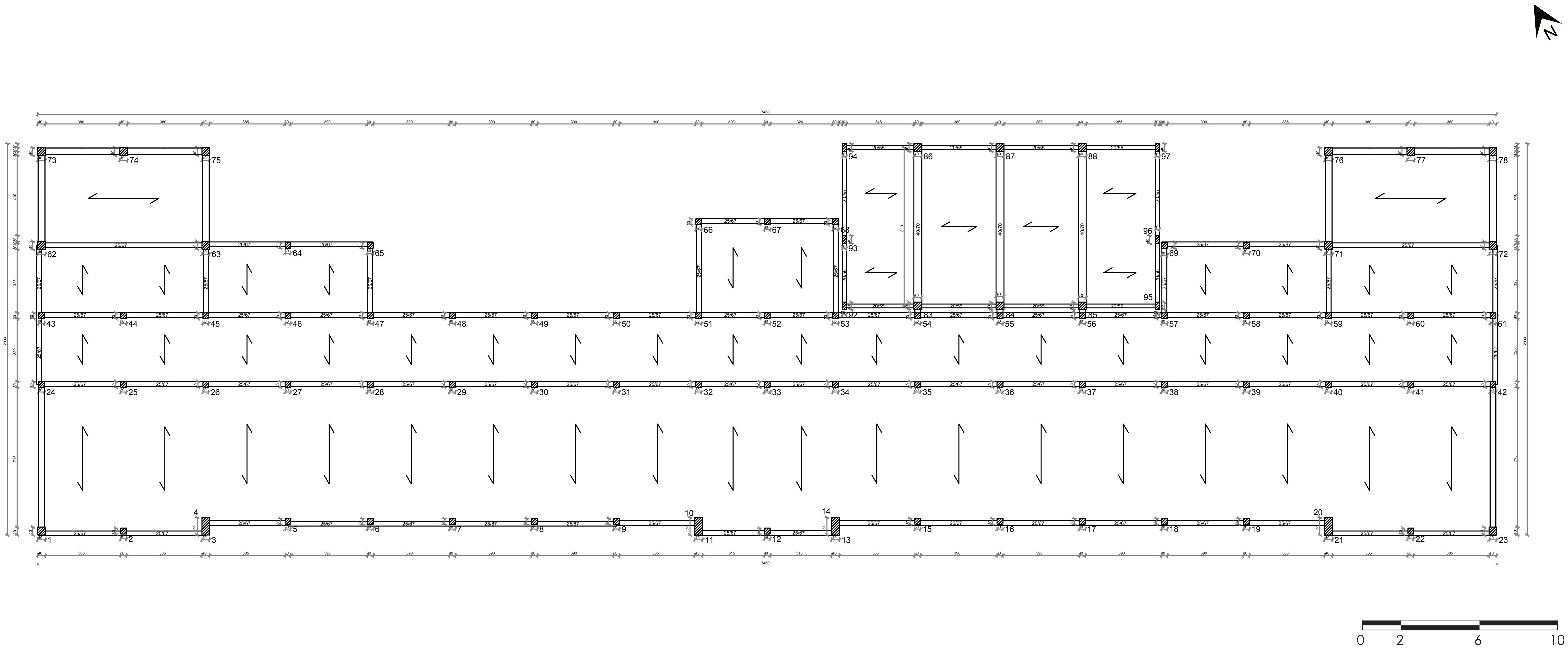


Figure 17. Second Floor Structural Plan
Quote + 14,80 m | Scale 1:200

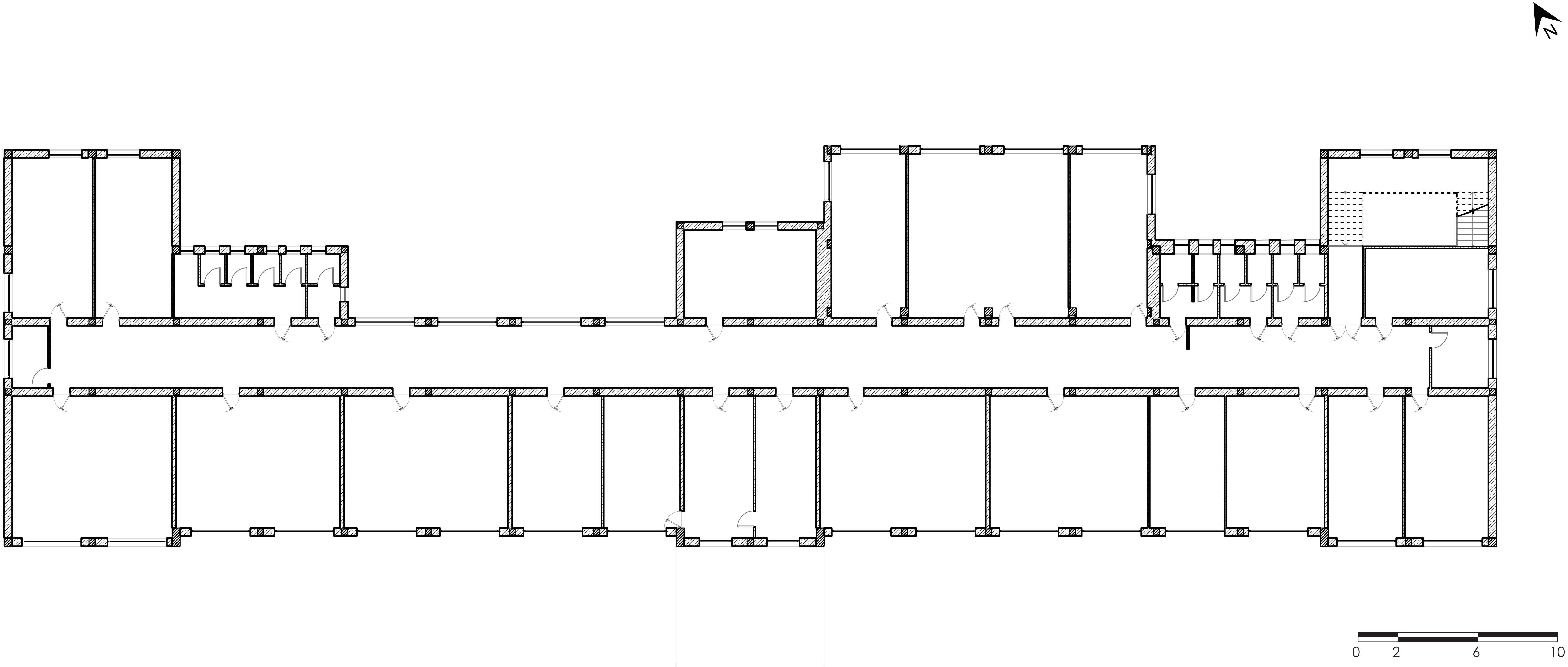


Figure 18. Second Floor Architectural Plan
Quote + 14,80 m | Scale 1:200

Figure 19. South Facade
Scale 1:200

Figure 20. North Facade
Scale 1:200

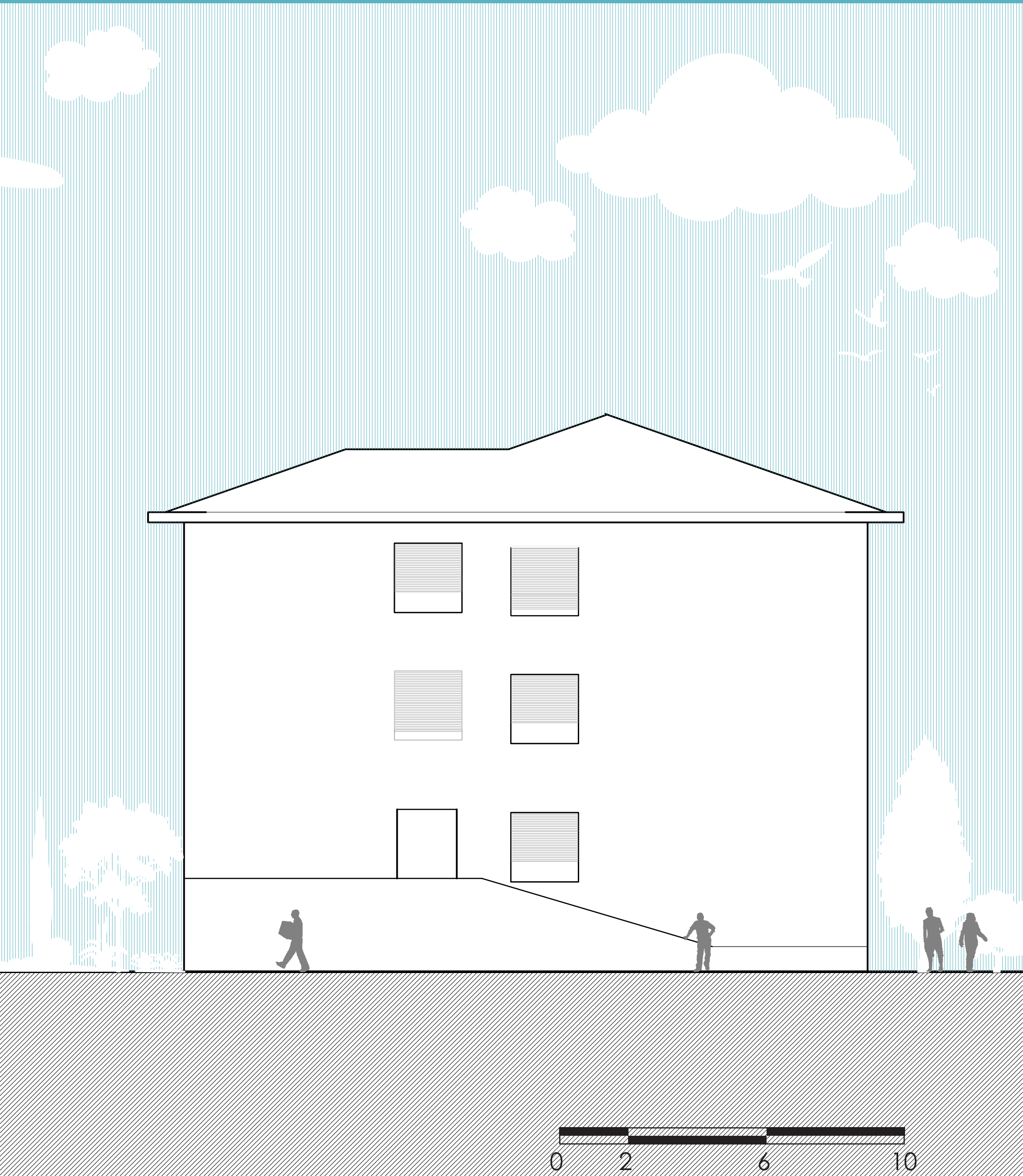


Figure 21. West Facade
Scale 1:200

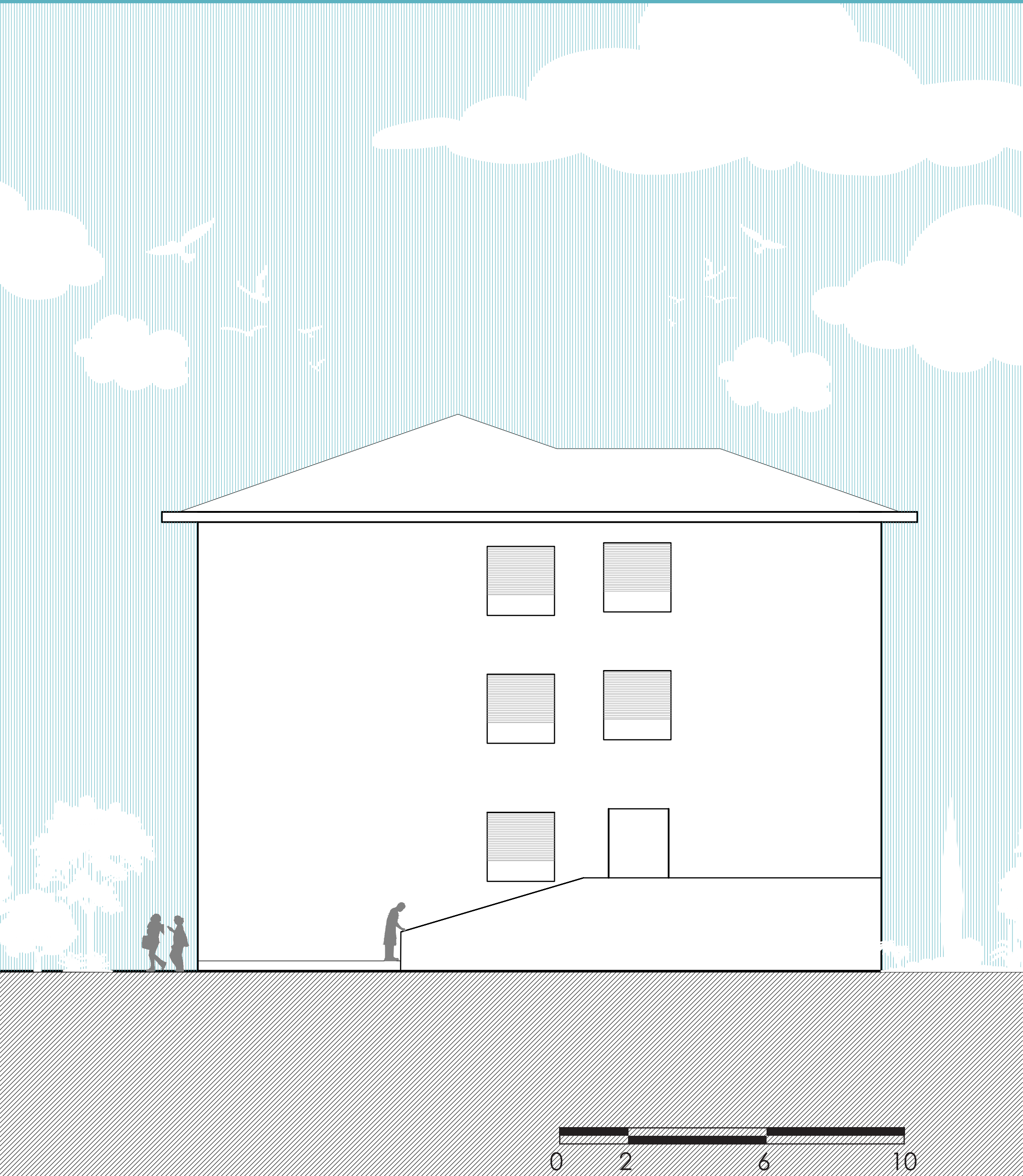
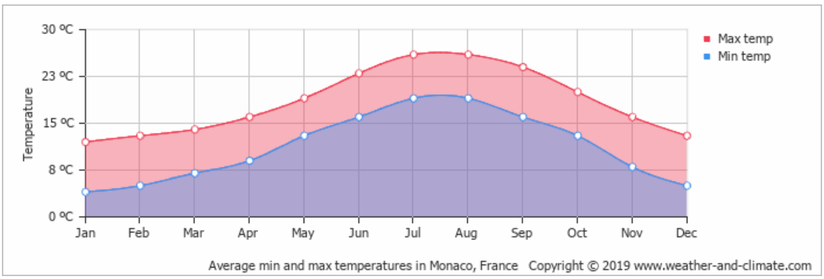


Figure 22. East Facade
Scale 1:200

4.3. Climatic conditions

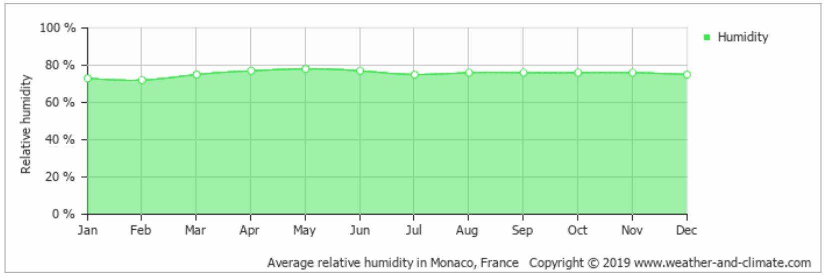
The city of Bordighera is characterized by its beautiful coast, making it an important touristic destination during summer. The fact of having the sea coast is what defines its climatic conditions.

The annual average temperature is 15.6°C, with an average of 23°C in summer and 9.5°C in winter. The highest temperature registered is 28°C in July and the lowest is 5°C in January [41-42].



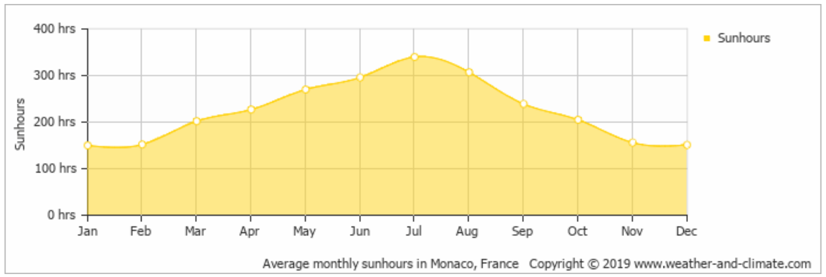
Graphic 1. Average temperature in Bordighera, Imperia [42]

Due to its proximity to the coast the humidity levels are in general pretty high, with an annual average of 75% [41-42].

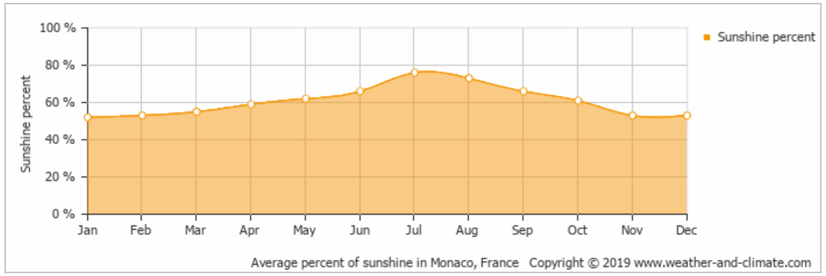


Graphic 2. Relative Humidity in Bordighera, Imperia [42]

The sun hours per day change every month according to the season, the monthly hours go from 150 hours in winter, in the shorter days where the sun last for an average of 8 hours; to 320 hours per month on summer, with the longest days where the sun lasts for an average of 15 hours. The sky is regularly pretty clear, so the percentage of sun received every day is quite elevated.

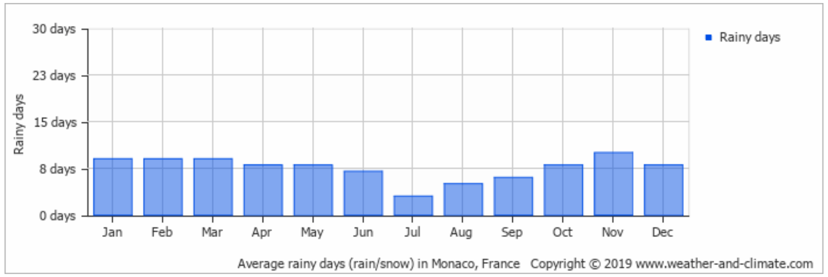


Graphic3. Average of sunhours in Bordighera, Imperia [42]

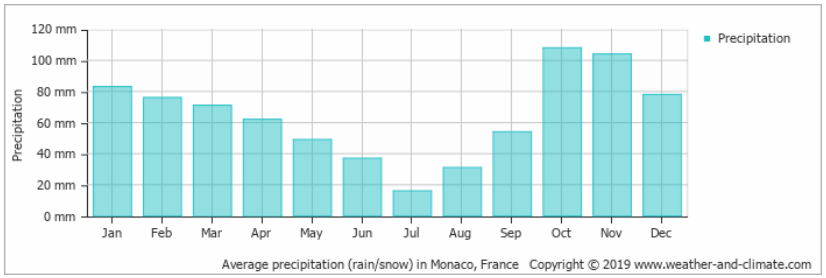


Graphic 4. Sunshine percent in Bordighera, Imperia [42]

On the other side, the rain situation is quite interesting. The driest month is July, while the month with the highest amount of rain is October. The annual average is 70mm, and the probabilities of rain in autumn, winter and spring are quite elevated. On the other hand, snow is not a big issue, since its probability is relatively low [41-42].

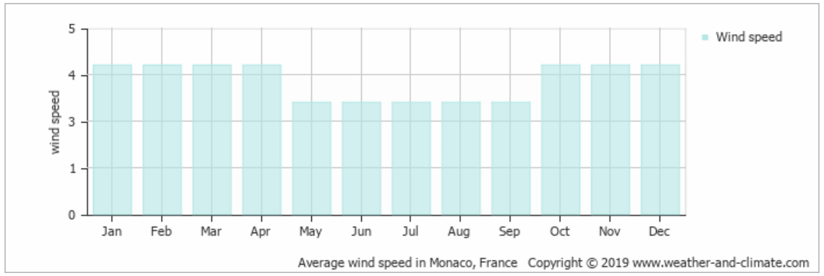


Graphic 5. Average rainy days in Bordighera, Imperia [42]]

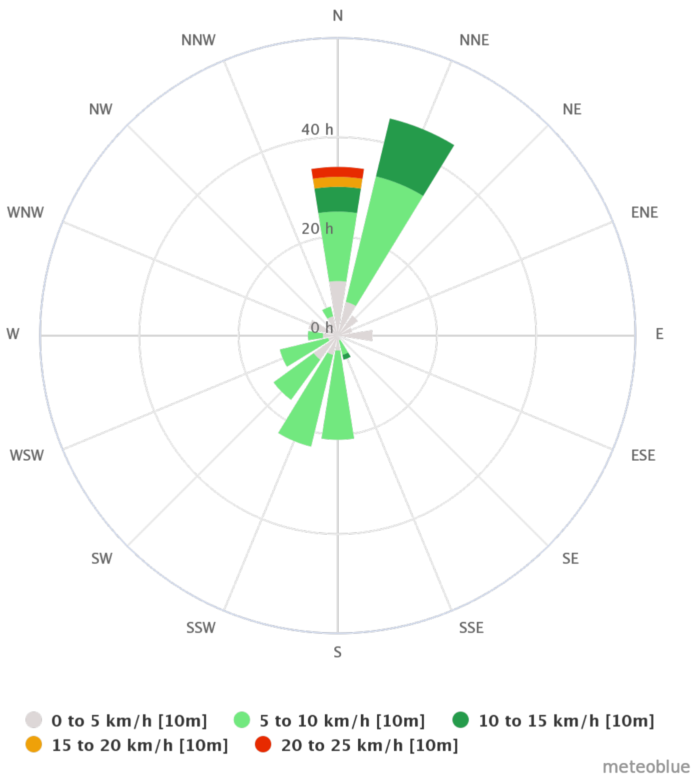


Graphic 6. Precipitation amount in Bordighera, Imperia [42]

Now for the wind, the average is 3.75 m/sec all year long, with a predominant direction coming from the east, which is the coast prevalent location.



Graphic 7. Wind Speed in Bordighera, Imperia [42]



Graphic 8. Wind Rose in Bordighera, Imperia [43]

4.4. Existent structural scheme

As said before, the building is an isolated construction of three main floors over a basement. The floor plan is irregular achieving the measurements of around 75 meters length per 20 meter wide, and a construction area of 1240 square meters approximately.

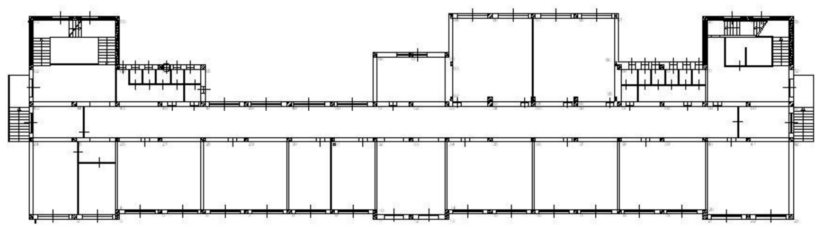


Figure 23. Typical floor plan | No scale

The structure is a typical construction of the years '50, characterized by the use of reinforced concrete for a fast and efficient construction process. Concrete frames are develop only and all along the longitudinal direction, consisting in pillars and lowered beams; the vertical bearing elements are positioned at regular intervals keeping the beams' lights in small dimensions. On the other hand, the frames are easily and entirely identifiable due to the presence of lowered beams and pillars that emerge from the perimeter walls and dividing partitions.

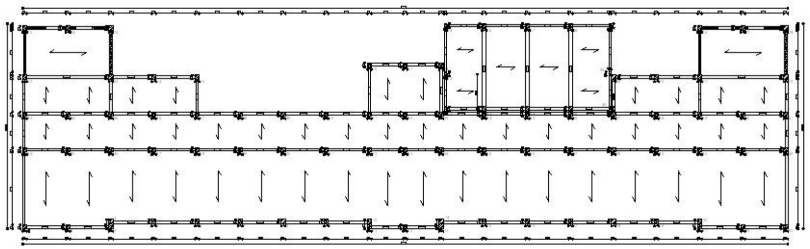


Figure 24. Structural floor plan | No scale

Each floor has an average of 3.40 meter high, they are built in lightened concrete with a thickness of 24cm. During the years the building has maintained its original structure without undergoing significant modifications, a single extension was built along the back side of the building, north oriented façade, around 1970 to increase the availability of teacher's facilities. This expanding volume was constructed also in reinforced concrete and it is placed nearby to the original structure, separated from it by several joints.

Its expansion is quite small compared to the rest of the building, it develops for the entire height of the building and has approximate measurements of 16 meters length per 8.50 meters wide. The volume's structure is composed by reinforce concrete frames, which consist of pillars and lowered beams that develop in both directions, the inter-floors and slab composition are equal to the original structure.

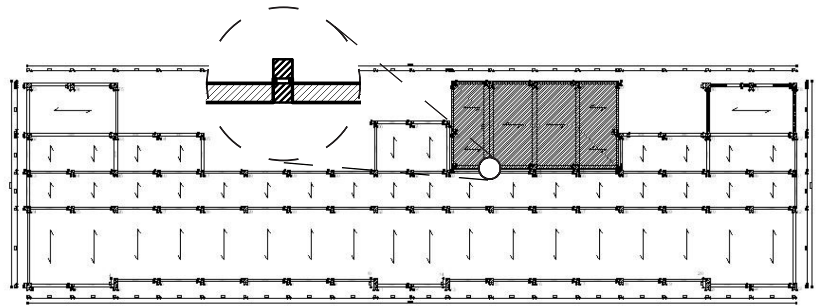


Figure 25. Expanding volume and joint detail | No scale

4.5. Structural state of preservation

In order to analyze the structural behavior of the building, it was necessary to model it with the software CDS Win, as it allows to create an accurate and detailed structural model, therefore the calculation verifications, results and simulations are very precise.

It is important to remark that all the calculation processes are based on the Italian Technic Regulation for Constructions NTC 2018, which follows the EuroCodes.

Modelling the building

The structural model includes the main body of the building with the expanding volume. It is important to quote that even if both structures, original building and expanding volume, are physically separated, the separation joints are not sufficient to guarantee the free movement of the structures in the event of an earthquake, that is the reason why they have to be modelled together. In the model, the involvement of non-structural elements was omitted.

First of all, a frame has been created in such a way to hypothesize the individual deck as infinitely rigid. This hypothesis is supported by the type of floor which provides a structural slab with a thickness greater than 4cm. Hence, each floor is determinate by three degree of freedom, two translations along the horizontal directions, X and Y of the center of gravity of the surface itself and the rotation around the vertical axis Z.

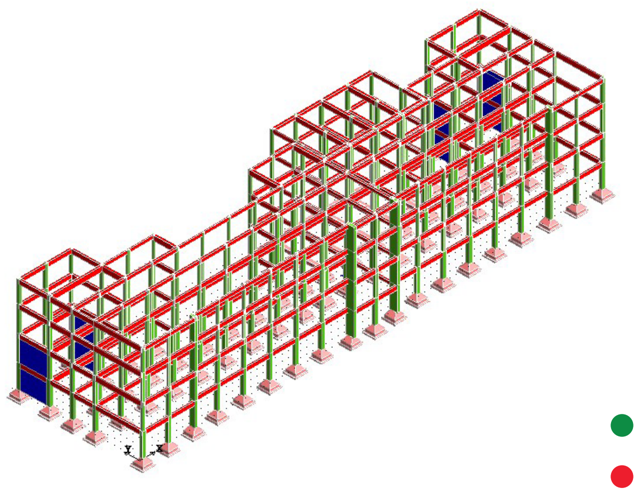


Figure 26. Model of the existent structure

Analysis of the model and results

The carried out analysis were of two types: the dynamic linear or modal analysis, which makes possible to derive, along with the several results, the maximum plane movements; and the push-over or non-linear static analysis, which expresses the data about stiffness and the calculation of the materials.

More specifically, the first analysis allows to assess the collapse of the building, by applying a distribution of incremental horizontal forces, which brings the structure beyond the linear field, until its own collapse. For this analysis, the applied forces are controlled in order to increase the horizontal displacement according to a control point in the structure, which is usually identified as the center of gravity of the upper floor.

As a result, from the dynamic analysis the following maximum displacement, which characterize the higher level of the building, has been obtained for each direction:

δ_max (mm)	
Direction x	47,70
Direction y	52,75

Table 1. Maximum floor displacements, existing structure

The software also illustrates the structural elements that satisfy or not the shear and press-flexure verifications by coloring them in green or red. The next figure illustrates the structural elements of the building after the verification were carried on:

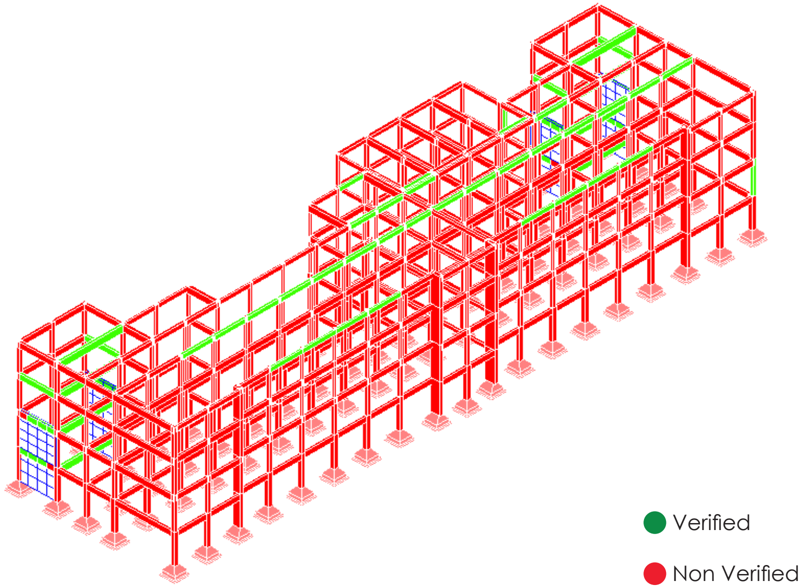


Figure 27. SLU Verification on the existent structure

As illustrated by the analysis, the school structure does not meet the safety requirements expressed by the European standards, making clear the big necessity for an urgent adjustment intervention.

4.6. Environmental performance

The aim of the project is not only to adjust the structural behavior of the building, but also to take advantage of the new structure that will be designed for the building in order to enhance its current performance, from the comfort conditions of the building to the carbon emissions and the energetic performance.

In order to achieve such result, first it was necessary to model the building in the software Design Builder. The program allows to calculate the environmental behavior of the building by modeling a simple 3d and specifying all its characteristics, such as the walls, floors, roofs, glazing and frames materials, the activities developed inside the building, the amount of people inhabiting in the building, the kind of equipment, and so on.

Modelling the building

First of all, it was necessary to indicate to the software the location of the building; conveniently the program counts with a large library of locations, activities, materials and so on, which is not only periodically updated, but is elaborated according to each location regulations and standards. The assessment area in the program is called “Costa Mela” as it is the place from where the database grabs the climatic information to work with. The next step is to indicate to the program the kind of use the building has, also selected from the library.

Once the basic information is established it is possible to start modelling the building. This step is quite simple, as it is only necessary to draw the perimeter shape of the building and make an extrusion of it, according to the height of each floor. After that, windows and internal divisions can be quickly modelled. For the model, it is not necessary to draw neither the structure nor the walls thickness, as they are not relevant to the program to carry on with the calculations.

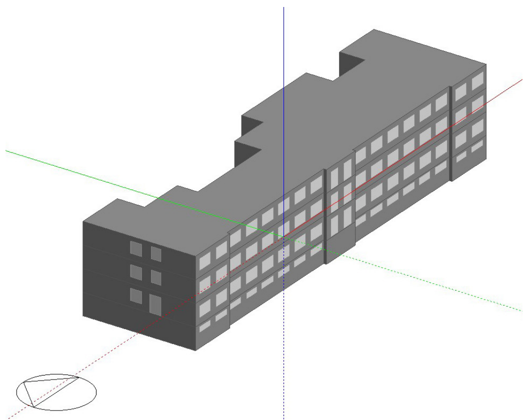


Figure 28. Design Builder model of the original structure

The final step is to indicate to the program all of the building’s specifications, such as the construction materials, glazing, type of glazing, heating system and location, cooling system and location, other equipment like computers, kitchen, and other; particular developed activities, and so on. As the building was constructed around years 1950, and the known characteristic is that it is a reinforced concrete structure, the aspects indicated to the program were the standards of a typical reinforce concrete building located in Italy, with high school activity and 300 inhabitants.

Analysis of the building’s performance

The first step is to specify to the program the various analysis to realize. It was indicated to the program to carry on with the following analysis, for the winter and summer typical weeks:

- Sun path diagram and shadowing
- Surface heat transfer
- Environmental performance
- Internal gains, including solar gains
- Energy, HVAC, etc
- Temperature distribution
- Comfort and environmental reports
- LEED Summary

Typical winter week results

- **Sun Path diagram and shadowing:**

According to the render elaborated by the software, under the location characteristics, during winter the solar azimuth is around 11.30am, with a prevalence of the sun to be oriented towards the northeast, with an average of 8 hours of sun per day. According to this result, natural illumination from the north façade should be prioritize, as much as the location for solar panels.

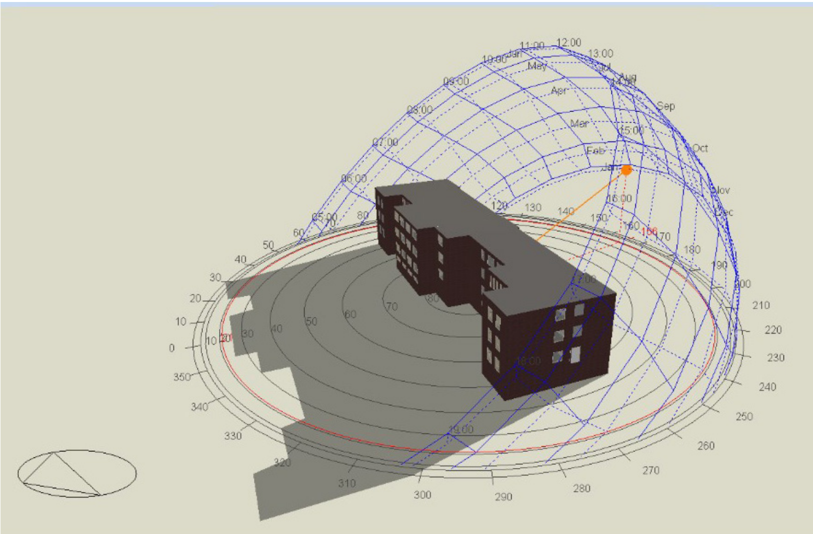
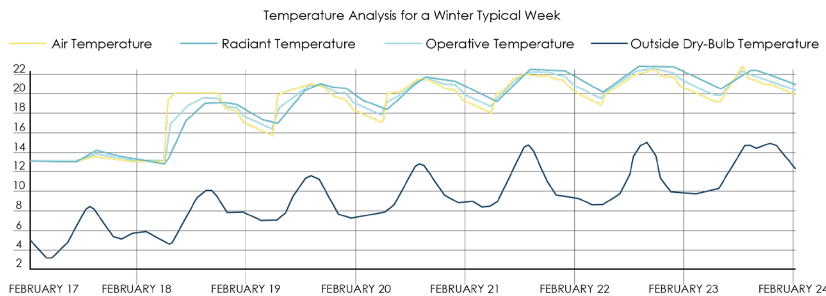


Figure 29. Sun path and shadowing rendering for typical winter day at 11:00am

- **Comfort analysis:**

This kind of analysis takes out two different outputs, one that illustrates the temperature situation and another one about the relative internal humidity. For the internal temperature, first of all it is important to understand what the terms make reference to. The air temperature is the temperature related to the air exchange between each zone of the building, and it is influenced by the natural ventilation if is present, and the cooling/heating system. The radiant temperature instead, is the temperature the user feels in the middle of a room without heavy clothes on, while the operative temperature makes reference to the average between the first two types of temperature indicators. On the other hand, the outside dry-bulb temperature is no other than the average of the external temperature.

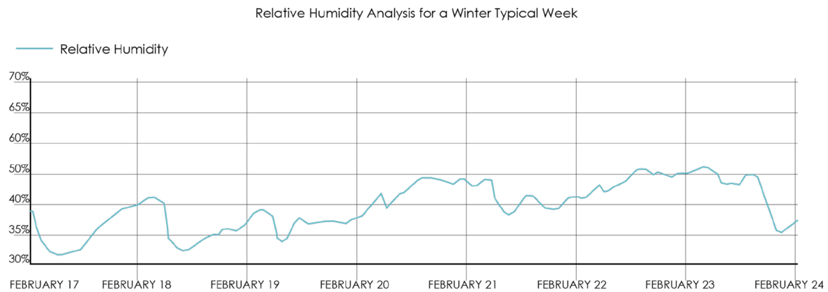
As result, due to the heating system, the building keeps an average temperature of 20°C, with the radiant temperature just a little bit above the air temperature, concluding in a pretty constant internal temperature during winter, good for comfort.



Graphic 9. Temperature analysis for a winter typical week

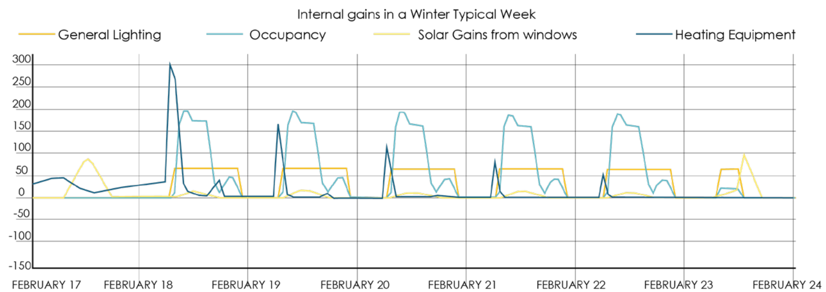
On the other side, even if the relative humidity external levels of the area are quite elevated, always over the 60% (take reference from the point 2. Climatic conditions of this chapter), the internal relative humidity is lower, with an average of 35% during the winter.

In conclusion, even if the internal temperature is good for comfort, the relative humidity inside the building suggests that the thermal sensation is colder.



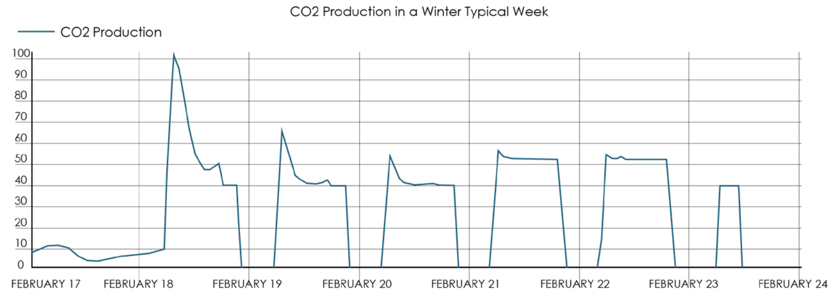
Graphic 10. Relative humidity analysis for a winter typical week

- **Internal gains:**



Graphic 11. Internal gains analysis for a winter typical week

- **CO2 production:**



Graphic 12. CO2 production in a winter typical week

Typical summer week results

- **Sun Path diagram and shadowing:**

The elaborated render illustrates that during summer the solar azimuth is around 3:00pm, with a prevalence of the sun to be oriented towards the northeast, with an average of 15 hours of sun per day. During this time of the year, the sun makes a full surrounding of the building, from the east side to the west, and it has a higher position compared to the winter Sun path.

According to this result, natural illumination is possible from every façade, at different time of the day. As for the possibility of locating solar panel in the project's proposal, it is possible to acquire energy almost from every side of the building, as its perimeter is not close, in other terms, the building is sufficiently isolated to receive solar radiation from all sides

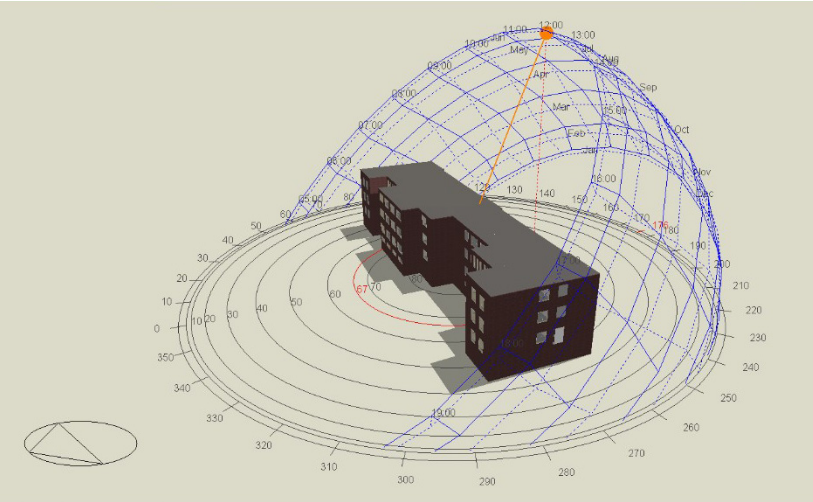
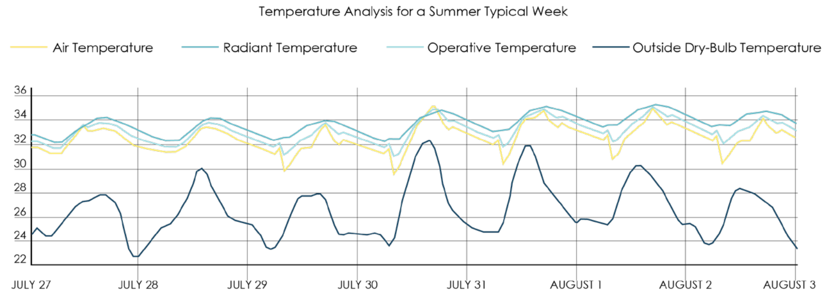


Figure 30. Sun path and shadowing rendering for typical summer day at 3:00 pm

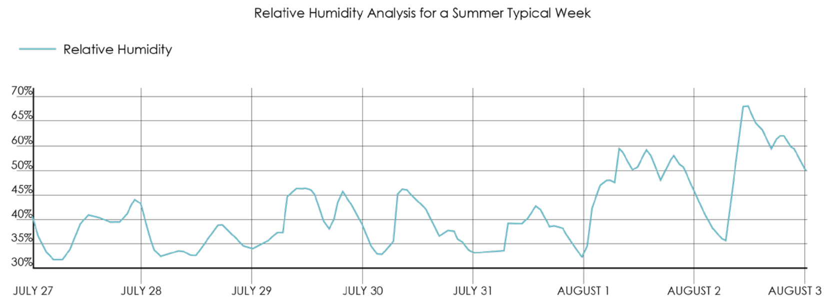
- ## Comfort analysis:

The graphic illustrates the comfort qualities of the building during a summer typical week. It was selected for the analysis a period of time between 27 July and 2 August. During this time, it is clear that the building maintains an average temperature of 34°C, with the radiant temperature above the air temperature, with a constant difference of 2°C. In general, the temperature goes up and down along the day, at it is significantly warmer inside than outside, as the building does not have cooling systems.

On the other side, even if the relative humidity external levels of the area are quite elevated and constant, always around the 60% (take reference from the point 2. Climatic conditions of this chapter), the internal relative humidity is lower, with an average of 50% during the summer, with significant risings during rainy days.



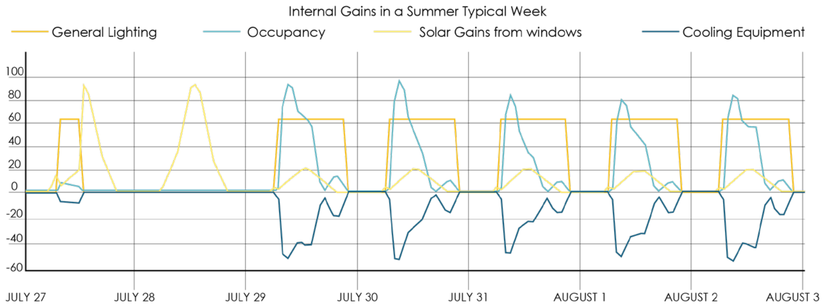
Graphic 13. Temperature analysis for a summer typical week



Graphic 14. Relative humidity analysis for a summer typical week

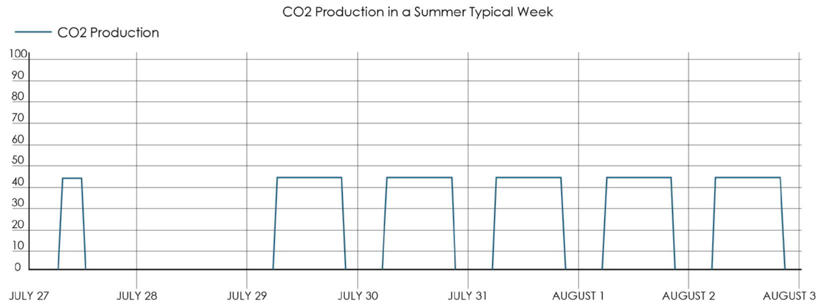
Overall, the internal temperature during summer is pretty elevated, achieving temperatures of 35°C with a significant humidity of 50% in average, which make the thermal sensation seriously warm, and therefore no good for comfort.

- **Internal gains:**



Graphic 15. Internal gains analysis for a summer typical week

- **CO2 production:**



Graphic 16. CO2 production in a winter typical week

Year average results

- **Embodied energy:**

	Area (m2)	Embodied Carbon (kg Co2)	Equivalent C02 emissions (kg Co2)
Building total	12870,50	354075,10	412250,0

Table 2. Embodied energy of Giovanni Ruffini's High School

- **LEED NC 2.2 Credit EQ 8.1:**

The aim of the daylighting credit is to encourage and recognize designs that provide appropriate levels of daylight for building users. A pass requires at least 75% of net lettable area in occupied spaces to be adequately daylit, having illuminance over the minimum threshold value. The results shown below were calculated using the Radiance simulation engine which provides a detailed multi-zone physics-based calculation of illumination levels on the working planes of the building.

Daylighting data	
Project file	C:\Users\Marianna\Desktop\TESIS\SUSTAINABLE CALCULATIONS\ORIGINAL BUILDING\SCUOLA RUFFINI.dsb
Sky model	CIE overcast day
Location	CAPO MELE
Working plane height (m)	0,750
Max Grid Size (m)	0,300
Min Grid Size (m)	0,300
Illuminance lower threshold	269,098

Table 3. LEED Illuminance analysis input

Summary Results	
Total area (m2)	4205,010
Total area meeting requirements (m2)	1097,254
% area meeting requirements	26,1
LEED NC 2.2 Credit EQ 8.1 Status	FAIL

Table 4. LEED Illuminance analysis output

SWOT analysis

5.1. SWOT Analysis

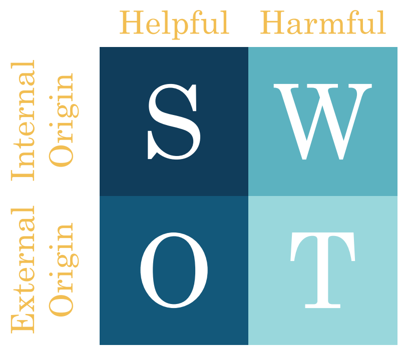


Figure 31. SWOT Analysis Graphic

The SWOT analysis is an useful planning method which allows an organization to identify the Strengths, Weaknesses, Opportunities and Threats related to the project. It is aimed to easily identify the mains objectives of the project and the approach to follow in order to establish a proper strategy, by identifying the internal and external factors that are favorable or unfavorable to the project.

The internal aspects are all those aspect strictly related to the project and that can be controlled, modified, retrofitted, while the external features are related to the context of the project, and therefore they cannot be modified [44]

5.2. Strengths

- The almost regular shape of the building.
- The regularity of the original structure.
- The facades are almost clear from outstanding elements, such as balconies.

The strength points of a project are represented by all those aspects of the building which can be taken into advantage for the intervention, and they must be improved, consolidated and/or highlighted.

For start, a seismic resistant structure works better when it represents a regular geometrical shape. The building, almost represents a regular rectangle, in order to complete it, the new structure must fill the lack spaces, creating an opportunity to add new stories to the original building, which can be used to cover the lack of some activities or to create new dynamics into the building.

On the other hand, original structure is quite regular, even the last addition of the building maintains the axes of the existing structure. This eases the job to develop and assembly of a new exoskeleton to improve the structural behavior of the existent building, because the new structure can follow without issues the existent structural axes to work in harmony with the building.

The lack of exterior element in the facades, such as balconies and other architectural elements represent a point of strength for the implementation of the exoskeleton, as it is not necessary the removal of any existing elements to start constructing it.

5.3. Weaknesses

- A vast range of structural deficiencies.
- Poor natural illumination and ventilation inside the building.
- Elevated energetic demand.
- Building with an obsolete architectural image.
- Absence of an efficient vertical circulation core.
- Lack of a sportive and multipurpose area of its own.

The weakness point of a project, on the other hand, are represented by all those critical aspects of the building that have to be solved, eliminated or contained. Therefore, they are crucial into the developing of the proposal.

The most critical point in the project is the vast range of structural deficiencies, and it is the principal reason of the intervention. This is the aspect that gives also shape to the proposal, as it is aimed to solve all this issues.

The building, as it was constructed in a moment were the necessity was to solve in a short amount of time the housing demand, it had a poor architectural quality, therefore, external aspects like the use of the environmental conditions of the area were not taken into account for the project. As a result, aspects like natural ventilation and illumination are of poor quality, and the energy demand is elevated. Because of the time of its construction, the building's image is the one of a prefabricated building, a generic building to be place in a plot in order to solve an issue, therefore its image is not only obsolete, but also lacks of identity.

Even if the building has 2 group sof stairs, placed on its lateral areas, they do not allow a complete circulation through the building, a group of stairs allows to move from the first floor to the second floor, while the other allows to circulate from the underground level to the ground floor. The building does not count with an elevator or any other system to allow free movement for disable people.

The School shares a gym with the community, and it does not compress an area for multiple cultural uses. This represents an important use to include into the project.

5.5. Opportunities

- The isolated condition of the building inside the plot.
- The building's orientation.
- Climatic conditions of the area.
- Clear area for further expansion.
- The use of the building as a school.

This point represents all the outward aspects of the building that even if they cannot be controlled, they represent an important feature that can be exploit in the favor of the proposal.

One of the most important requirements for the implementation of an exoskeleton is that the building has to be isolated from other structures, there has to be enough space in the facades' surroundings in order to construct the exoskeleton. The building achieves this particular condition.

The buildings orientation is also proficient in order to take advantage of the climatic conditions of the area, as the larger facades are in correspondence of the Sun's path and the building's position is favorable to take into advantage the wind's prevalent direction. Climatic conditions by themselves also represent an opportunity to the project, as they allow the implementation of different approaches in order to enhance the building's environmental performance. Due this conditions, it is possible to assess the implementation of solar panels, green walls, secondary hybrid skin, and more other technological innovative approaches.

The plot is also clear enough to permit any needed expansion of the building, and the use of the building as a school not only allows an easy construction process during school vacations, but also places the intervention into a high priority project, to preserve the life of children in case of an earthquake. Also by being an edifice of public administration, from 2019 the building must achieve the NZEB standards, therefore the improvement and implementation of technologies to reduce the buildings emission is mandatory.

5.5. Threats

- Limited possibility for intervention in the back side of the building, specifically on the north façade.
- Lack of projects with similar applications.

On the other side, the treats are all those external characteristics which cannot be eliminated and consequently must be mitigated through the application of different approaches.

Talking about the main requirement for the construction of an exoskeleton which is the available space in the building's surroundings, the building already achieves the separation requirements between isolated buildings dictated by the urban regulations, therefore, there is no possibility of expansion in the north façade of the building.

From another point of view, as this is a new type of intervention to fix the structural issues of existent buildings, there are not many developed projects of similar application worldwide, which can represent a lack of confidence into the users regarding the seismic performance of the building. The image is also important in order to aid the people reception to the proposal, as the only exoskeleton can give the impression of an endless restoring work to a building.

6

The architectural concept

6

6.1. The architectural concept

In a new building's project, the approach to define the architectonic proposal is quite mechanical, in fact there are a series of steps to follow. To begin with, it is important to understand the plot, the urban laws and the limits for the design. Later on, the context must be analyzed, not only on the physical aspect, such as the buildings, streets, heights, accesses, green areas, climatic conditions, but also the non-physical aspects of the area, such as the people, how the live the city, their culture, and so on. This aspects will define not only the aesthetic of the building, but also how the project is going to be assembled, how people will interact with it.

Even if it is not a project that starts from zero, the approach that defines the intervention is not so different. First of all, it is important to analyze the existing building, to understand its major problems, deficiencies, but also the things that may serve as an advantage to the proposal. Furthermore, the population, the inhabitants, must be recognized, understood, in order to identify their possible needs, if the lacks they feel are present in the current building. Generally speaking, the approach to define the intervention is carried into a smaller range of action, into a different objective.

As explained in the previous chapters regarding the exoskeleton, there are a series of possibilities when it comes to define how the project will be, and how the intervention will modify and/or influence, not only over the original project, but also over its context. Then, there are a few innovating steps, carried out with the "exoskeleton" type of intervention, which will prepare the building to a better connection with the new addition.

The first step is to identify if there is enough free area next to the façade, in which the foundations of the exoskeleton will be placed, also assessing the possibility of expansion. Elements like the roof and balconies must be removed in order to carry on with the intervention. Once the deficiencies of the building are identified from the structural point of view, the intervention can solve also issues of other matters, like lack of elevators, stairs, and the adding of new technologies to improve the performance of the building. For last, the new facades must be defined, renewing the entire image of the building.

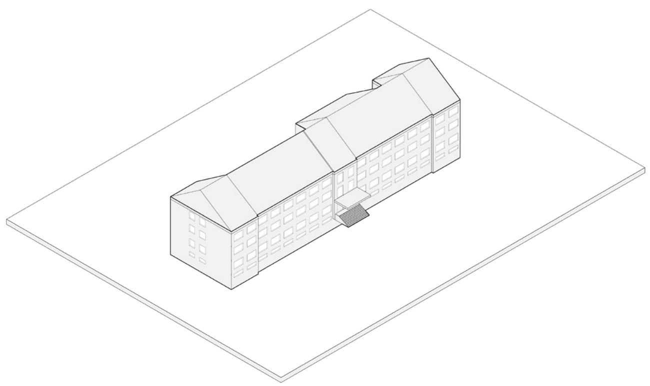


Figure 32. Giovanni Ruffini's High School Scheme

6.2. Giovanni Ruffini's High School intervention

The school, as described before, is in urgent need for an intervention to solve its structural deficiencies. Taking advantage to the imminent intervention, aspects like building expansion and performance improvement must be taken into account.

First of all, the plot was analyzed, identifying the available area to place the exoskeleton's foundations and the possibility for the building's expansion. The plot is favorable, as the building is complete isolated to its neighbors. The only limitation for expansion occurs in the north façade, in which the building is already at the minimum distance of separation required by the urban regulations, regarding to isolated buildings.

Anyhow, since the building does not have a regular shape, it is possible to add new stories in that area, that way regularizing the geometry of the building, which is a good characteristic for seismic structural improvements.

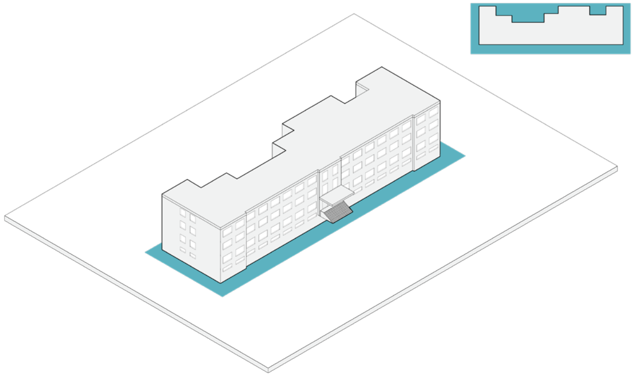


Figure 33. Available free area for expansion

In order to implement the exoskeleton, some elements of the building have to be removed, such as the roof and any existing balconies. The biggest issue was the access, as there is a concrete stair that enables the access to the first floor, but it was in the way to place the exoskeleton's foundations, and therefore, it has to be removed and reconceived. Balconies must also be redesign, in order to connect them to the exoskeleton's structure.

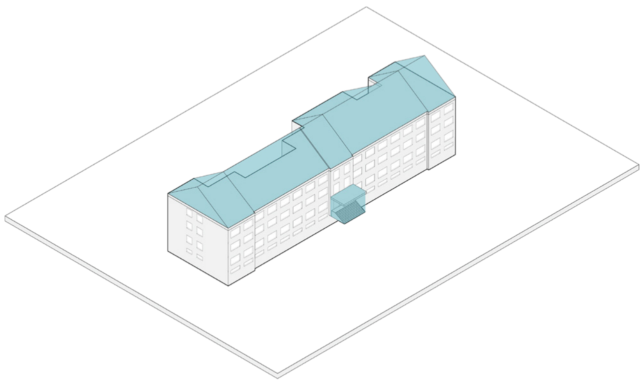


Figure 34. Removal of existing elements

After that, the architectural aspects of the building were identified in order to determine the lacks of the building. It was possible to notice the lack of an elevator, and the possibility to add another group of stairs,

making it easier to move through the building. It was also remarkable the necessity to create a strong core to help stiffen the edifice in its central part; therefore, this was the place selected to established the vertical circulation core, also because it is next to the principal access of the building, easing even more the circulation inside the structure.

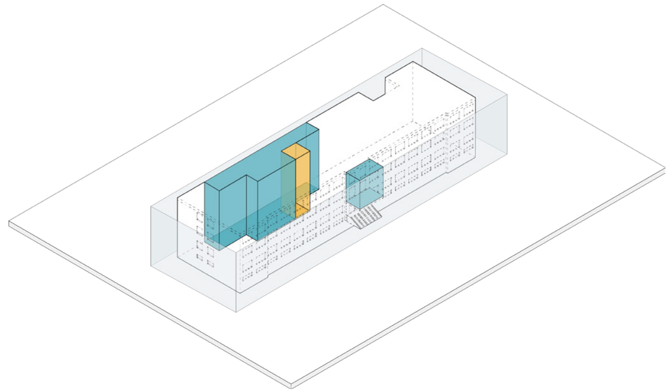


Figure 35. Addition of new areas and elevator

Once these first aspects were established, it was possible to define a first concept of how the exoskeleton might look, and more importantly, the type of materials to use and where type and location of the foundations were going to be.

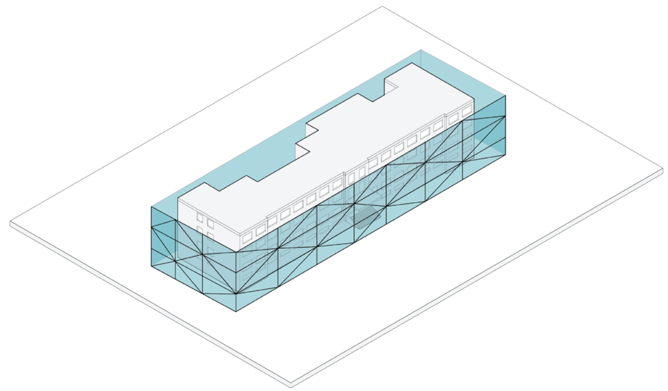


Figure 36. Structual reinforcement scheme

With a first sketch of the structure, it was important to start thinking about the aesthetic of new facades, and the new technologies to implement in order to also enhance the performance of the building. It was necessary to redefine the image of the access, giving it hierarchy from the other elements of the façade, offering to the user a fast identification of the building's principal access.

The possibilities for the aesthetic of the façades are many, so different concepts were assess. Analyzing the surroundings and the climatic aspects of the area was a tool to defining the best option for the façade, as the selection of the technologies to use. Between all of the existing options to apply for the enhancing of the building's performance, the selection was to go for green walls and solar panels.

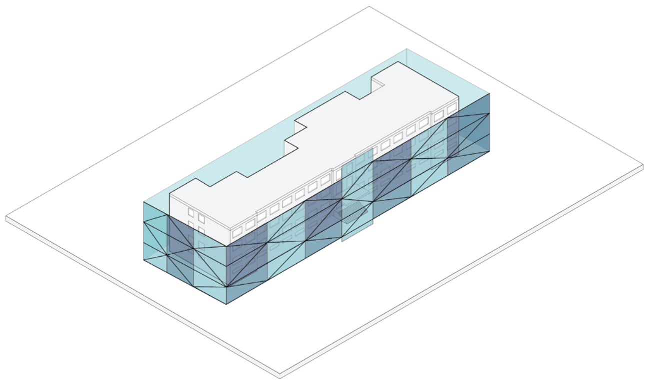


Figure 37. The exoskeleton's aesthetic concept

The implementation of green walls have a vast positive effects to the buildings, and also to the surroundings. Vegetation by itself, decreases the elevated temperatures of summer, as they provide a clean source of oxygen and humidity, as a result the temperature difference can achieve a top of 3 degrees minus the outdoor temperature. When applied to a façade, or

even a plot perimeter, vegetation creates a barrier against pollution, VOCs and sound contamination. It also represents a barrier against high speed winds, as it breaks the gust of wind. At a psychological level, it is proven that nature, vegetation, green, increases the level of happiness of people.

Therefore, introducing green walls into the project seems to be a feasible choice, also allowing students to interact with nature, as they study. Students can have their own farming experiments giving an image to their school, which also increases their feeling of identity for the building. Many new dynamics can be created with the implementation of this kind of façades into a building, and the advantages can only grow. Also, depending on how the structure for the green walls is projected, the maintenance can be minimal, avoiding it to be an issue that might affect the building's aesthetic in the future.

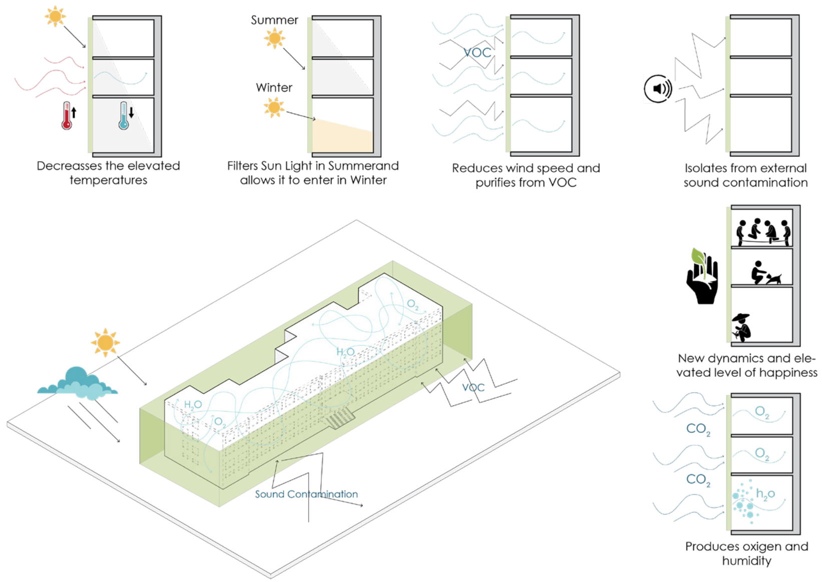


Figure 38. Green walls positive aspects

On the other hand, for the solar panels, it was necessary to understand how the building interacts with the sun, all year around, due to its location and orientation. Lateral facades and front facades are easily exposed to solar radiation all the year, while the north façade, the back part of the building, even if it still receives some radiation, it does not achieve the same records.

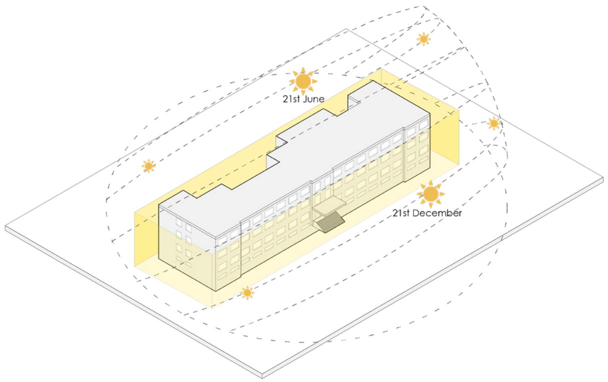


Figure 39. Solar path scheme of the building

There are several new technologies when it comes to solar panels, all really innovative. While researching, an interesting project came out. In Sweden, a company called Solaronix, elaborated a new technology of solar cells capable of being adapted to glasses while maintaining a remarkable level of transparence in them. The technology is also capable of catching a significant amount of solar radiation even in the darkest days of Sweden, which is an important feature as the days there are often cloudy and rainy, without taking in consideration the short days in winter.

They added to the material 3 different colors, to be placed serially, and the panels turn automatically in order to position themselves into the best angle to receive the solar radiation. The technology was tested into a building in Sweden, the "SwissTech Convention Center", in collaboration between the Solaronix Company, EPFL and the Richer Dahl Rocha architects. They located a total of 355 panels on the west side of the building. The panels with measures of 1 meter to 2.5 meters length, consisted into grouping modules of 50cm per 50cm.

The selection of colors for the panels had the goal to meet the overall light transmission target of the architects and to give a unique dynamic to the façade, as a result, the artist Catherine Bolle choose red, green and orange, to be place in a serial pattern, giving a smooth tone to the light transmitted inside the edifice. Therefore, the façade allowed to achieve two principal functions, the first one, was to passively prevent the incoming sunlight from overheating the area, while the second one, was to actively produce renewable energy from the sun to sustain the energy demand of the building [45].

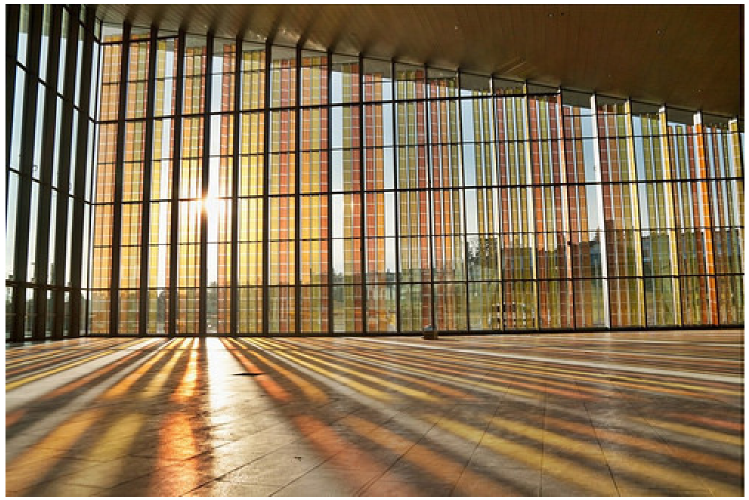
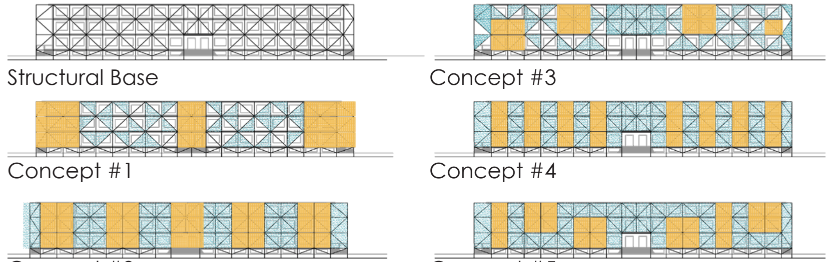


Figure 40. SwissTech Convention Center, internal view of the Solaronix solar cells [45]

Consequently, joining all these aspects into one image of a building opened a window of many possibilities. Several configurations were tested into choosing one image that was capable not only to significantly improve the buildings performance, but that was also harmonious to the context and the different activities developed inside the building. The final concept for the façade was to elaborate a regular pattern to be repeated according to the activities of the building, giving more importance to the sensations inside it, and how it could affect the everyday life of the users.

The pattern is therefore, a misture between green walls and solar cells for the lateral and front facades, while for the north facade, the decision was to exchange the solar cells for regular glazing, maintaining the selection or colors to keep the internal sentations and harmony of the entire complex. The permeability of this kind of skin, allows maintaining the visual of the exoskeleton, all year long, and the green walls introduce an everchanging facade, as its aesthetic depends on the selection of plants, their growth, and the current season.

The result is a dynamic living building, which aesthetic will depend not only in the current external conditions, but to the identity of the users towards it.



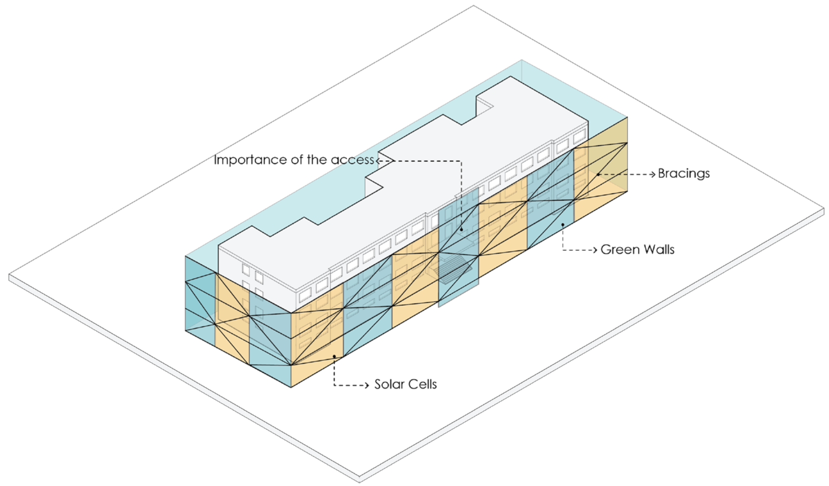


Figure 41. The facade aesthetic final concept

7

Development of the proposal

7

7.1. Development of the proposal

Once the architectonic concept was clear, the next step was to develop the structural part of the project. In order to assess the idea and verify if it was the best way to fix the original building's structural deficiencies while developing a nice renovation of the building's image, the result was to model the building and the exoskeleton with CDS Win software. As the aim was also to obtain a good aesthetic for the exoskeleton, the starting point was a light and subtle steel structure, with small sections for each structural element.

It is important to remark that all the calculation processes are based on the Italian Technic Regulation for Constructions NTC 2018, which follows the EuroCode

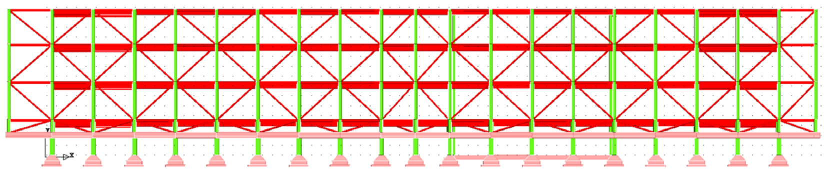


Figure 42. Model of the first attempt for the structure development

7.2. Structural test #1

As shown in figure 43, the columns of the exoskeleton followed the original structure of the building, separated along the back part of the building just enough to place the new foundations without interrupting the original ones. For the other sides of the building, the separation was enough to keep the stairs to the secondary entrances, while in the front of the building, the exoskeleton is separated of 4 meters, to enhance the second skin characteristics ans allow the implementation of balconies, as well as the possible expansion of the existent areas of the building.

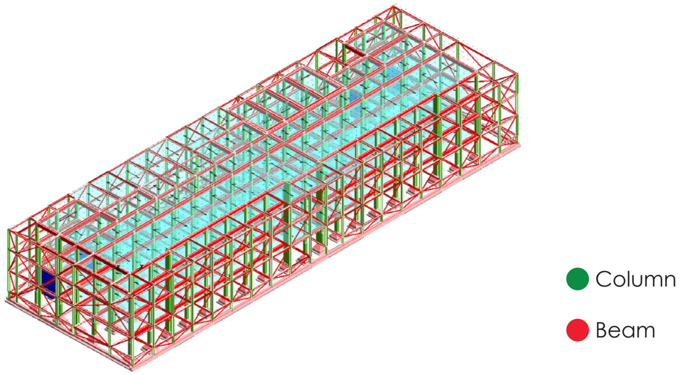


Figure 43. CDs WIN 3D model | Version 1

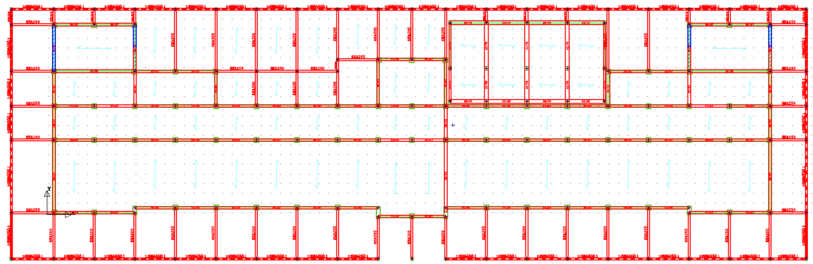


Figure 44. CDs WIN 3D model typical floor plan | Version 1

As shown in the model, bracings were used only in the facades with a section of diameter equal to 100cm, configured every 4 squares composed by the union of the columns and the beams. This open and lighter way to develop the exoskeleton gives the users a better visual from the exterior, and the feeling of a lightweight structure.

However, the first result was not even close to be good enough, as the calculation results illustrated the imminent collapse of it.

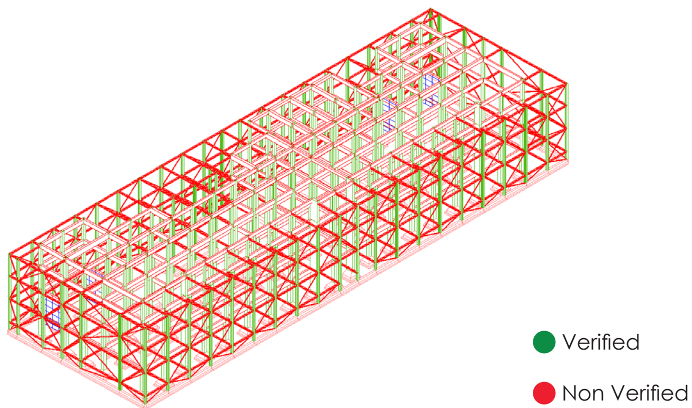


Figure 45. CDs WIN 3D model verification results | Version 1

7.3. Structural test #2

The first improvement to the structure was the implementation of the bracings in the horizontal way, in other words, the implementation of the bracings on each floor. Bracing were place in "X" for each structural square composed by the beams and pillars, while the section used remained as a tube with a diameter of 100cm. The modification is illustrated in figure 46, which represents the typical floor plan.

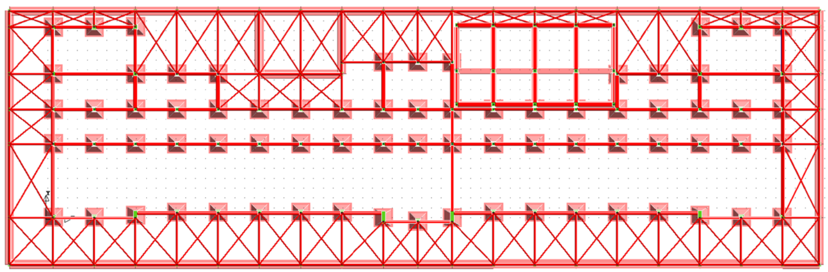


Figure 46. CDs WIN 3D model typical floor plan | Version 2

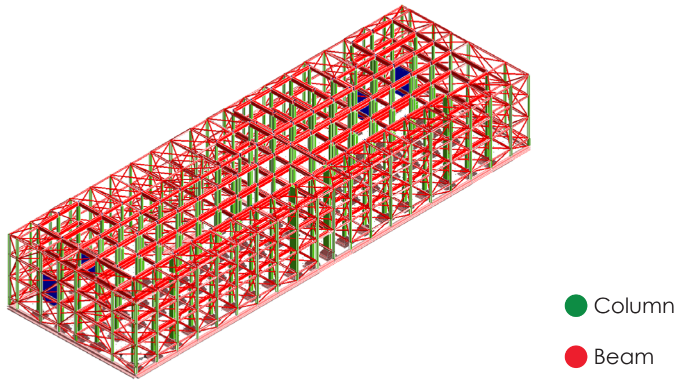


Figure 47. CDs WIN 3D model | Version 2

The results improved significantly, as the whole structure was no longer collapsing. However, there were still some critical points in the exoskeleton, and the structure was not rigid enough to solve the deficiencies of the original structure. The most worrying parts of the exoskeleton were the lateral ones and the irregular back part of the existing building, which were still imminent to collapse.

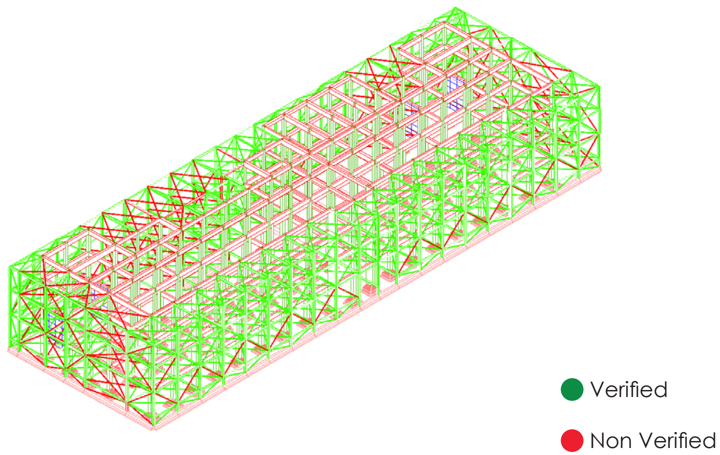


Figure 48. CDs WIN 3D model verification results for steel elements | Version 2

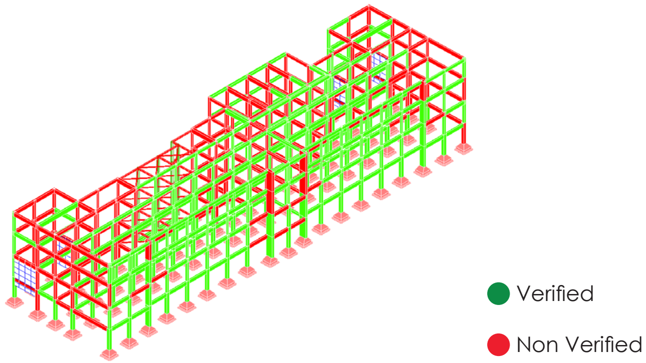


Figure 49. CDs WIN 3D model verification results for reinforce concrete elements | Version 2

7.4. Structural test #3

The subsequent decision was to improve the structure as a "C" shape on both sides. In this reinforced part of the exoskeleton, more bracings were added in vertical direction, perpendicular to the facades, and the section of all the bracings in this "C" area was changed from a diameter of 100 to a diameter of 120, adding more stiffness to the zone.

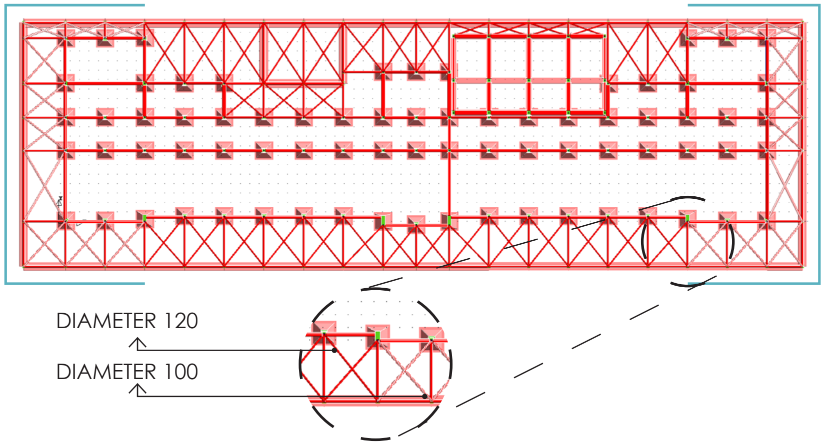


Figure 50. CDs WIN 3D model typical floor plan | Version 3

Even if the result has improved, it did not changed enough. The lateral parts of the structure were verified, while the back side of the original building was still in a critical situation, therefore a different approach was needed.

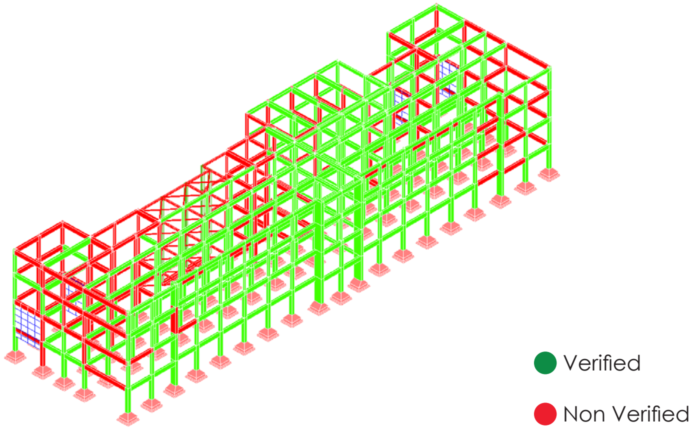


Figure 51. CDs WIN 3D model verification results for reinforced concrete elements | Version 3

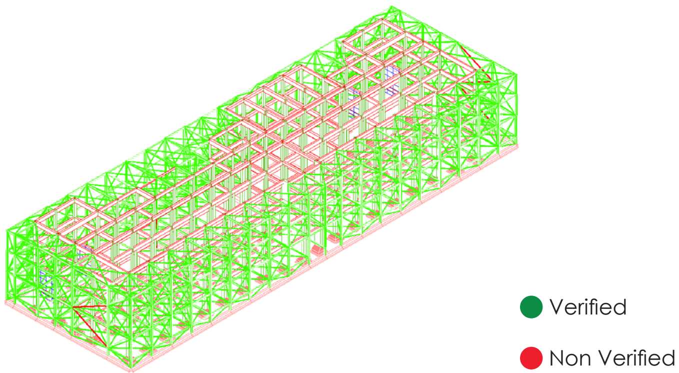


Figure 52. CDs WIN 3D model verification results for steel elements | Version 3

7.5. Structural test #4

As a different approach seemed the next step before enlarging the section of the bracings, the decision in this step was to add the bracings in a perpendicular direction regarding the facades, with a section of 120cm of diameter in the back part, which was the most critical area, and maintaining 100cm diameter for the front part, which was already verified.

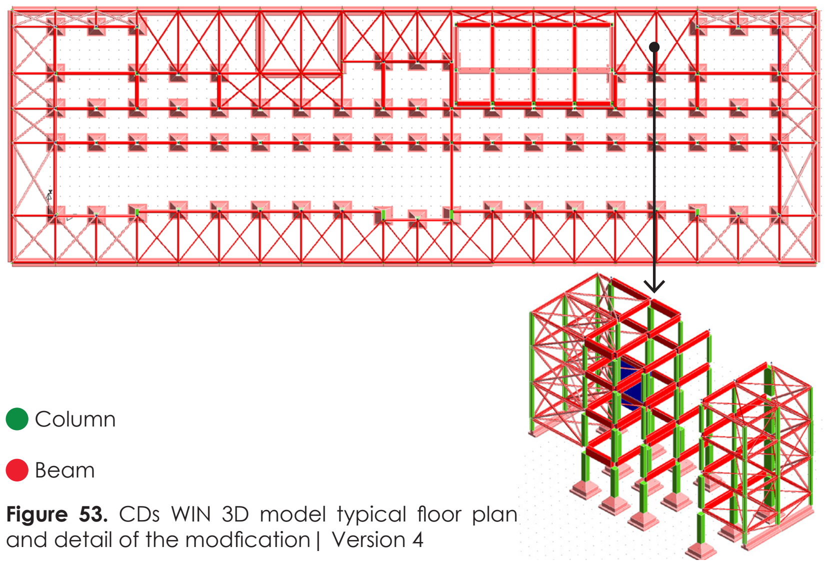


Figure 53. CDs WIN 3D model typical floor plan and detail of the modfication | Version 4

The result was quite shocking regarding what was expected. While the posterior area of the building was still collapsing, the front area and laterals of the building started to present some new troubles, as shown in figure 54.

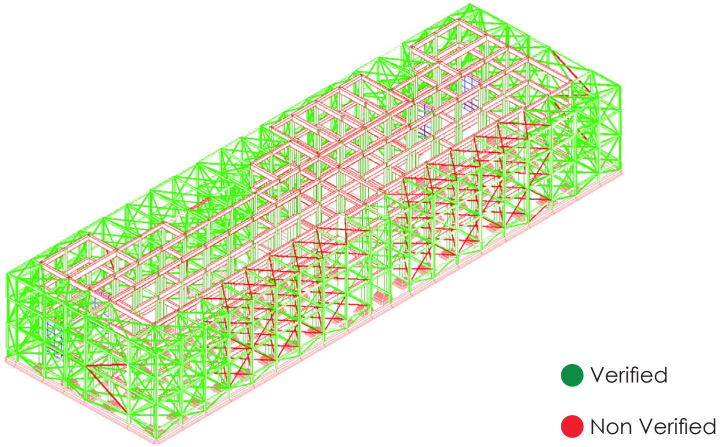


Figure 54. CDs WIN 3D model verification results for steel elements | Version 4

During a deep analysis of the simulation results, the center of gravity seemed to be the issue, as they had distanced significantly in the direction of the posterior façade. The comparison between the centers of gravity and stiffness of this test with the results of the previous one, revealed that they had significantly distanced from each other due to the great stiffness of the posterior

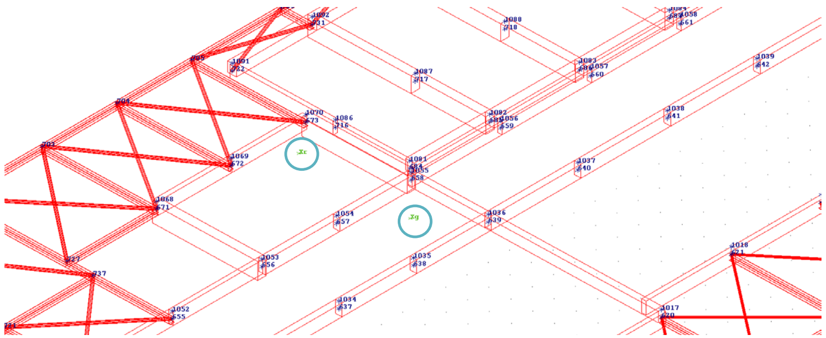


Figure 55. Centers of gravity and stiffness of the model | Version 4

area of the building. Also, the addition of the bracings in a perpendicular direction regarding the facades did not showed any improvement related to the stability of the whole structure.

Consequently, it was necessary to go one step behind, remove this bracings and to think into a different approach.

7.6. Structural test #5

The final solution was to enlarge the section of each bracing. Therefore, all the bracings composing the "C shape" reinforced area, in the laterals of the building, were changed from a section of diameter 120cm to a diameter of 160cm, while the rest of the bracings were enlarged from a section of diameter 100cm to a diameter of 120cm.

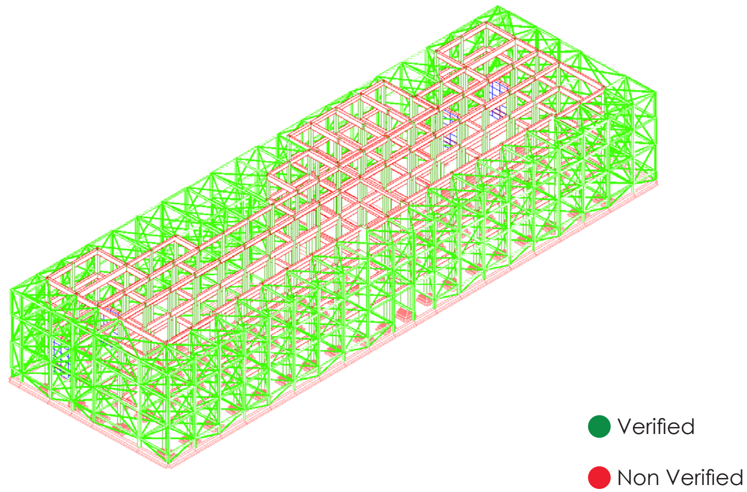


Figure 56. CDs WIN 3D model verification results for steel elements | Version 5

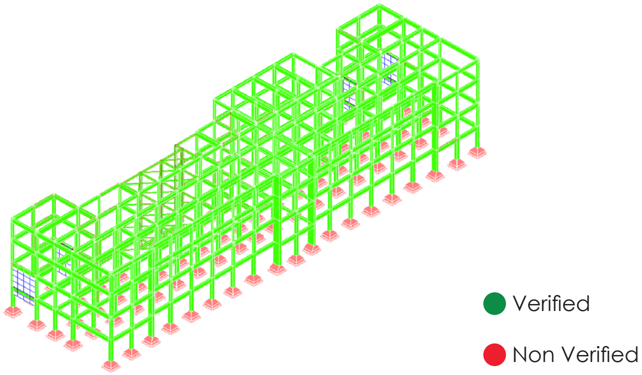


Figure 57. CDs WIN 3D model verification results for reinforce concrete elements | Version 5

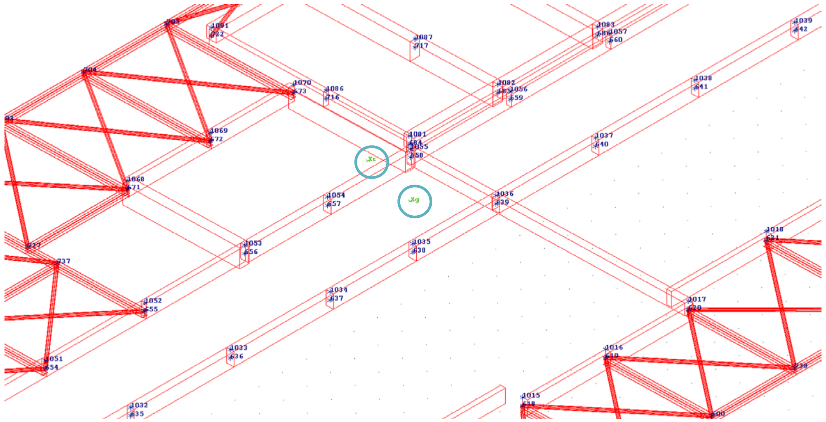


Figure 58. Centers of gravity and stiffness of the model | Version 5

As shown in the previous figures, the solution was accurate, not only the exoskeleton's structure reached the regulation standards but also the original structure was stable enough to fit the seismic standards. Moreover, while controlling the gravity center and stiffness of the building and the biggest displacements, either in X direction as in Y direction, all the values revealed to be significantly low, as shown in figures 59 and 60.

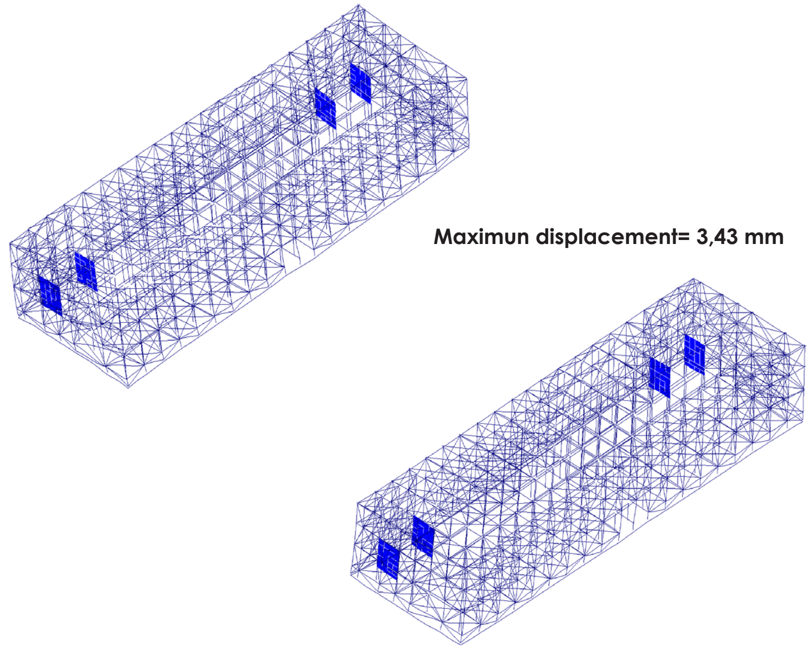


Figure 59. Displacement analysis of the model in direction "X" | Version 5

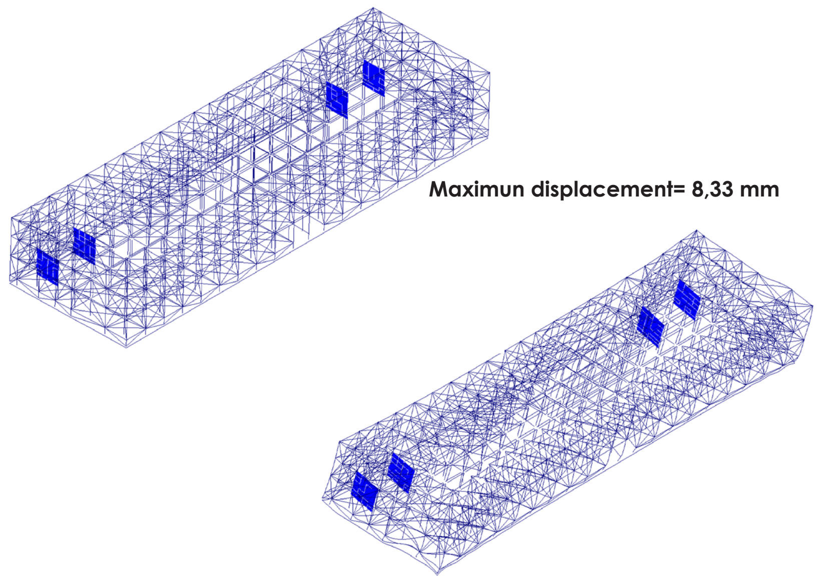


Figure 60. Displacement analysis of the model in direction "Y" | Version 5

7.7. Environmental performance analysis of the proposal

As explained in the previous chapter, the proposal to improve the performance of the building consists in the implementation of a second skin to the building, composed by green walls and solar cells, disposed along the façade in correspondence to the different activities developed in the building, with the aim of creating specific sensations.

In order to test these improvements and to verify how the second skin influences the building's behavior, the exoskeleton's skin was modelled with the software Design Builder, used first to verify the current building behavior. The aim was to achieve a type of project that would take advantage at the maximum level to the environmental conditions of the area, such as natural ventilation and illumination, humidity levels, wind speed and direction, and so on.

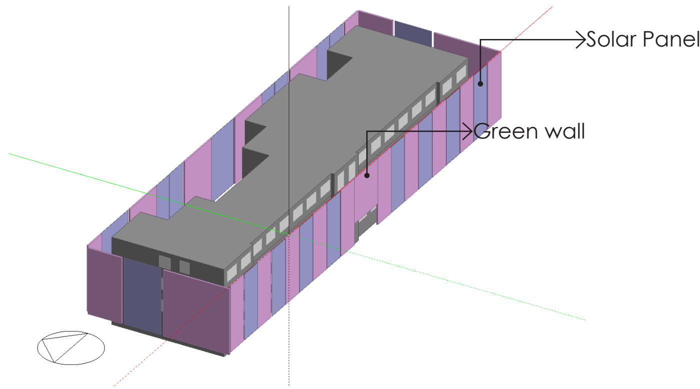


Figure 61. Design Builder Model with the exoskeleton's skin

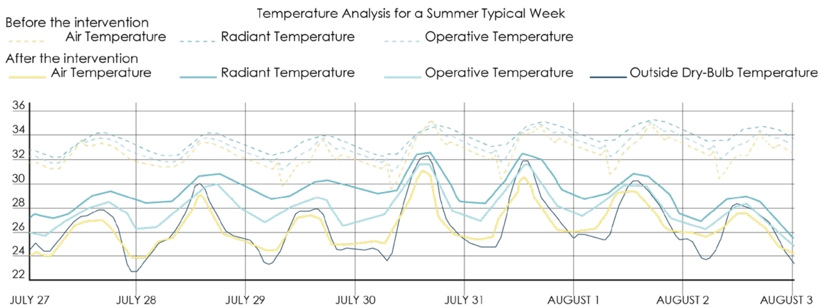
The program allows to elaborate an object completely individual to the original structure, and to give particular specifications to it. To model the green walls, an object was created with the condition of a second skin composed by a vertical garden, while for the solar panels, a group of glazing was creating, indicating the implementation of Solar Cells to this windows. All elements were displaced in the surroundings of the building's block, just as it was designed in the architectural concept.

As it was explained in the precedent chapters, the program does not take into account the building's structure to run the calculations, it does not even allow the modeling of structural elements, therefore the exoskeleton's structure is not necessary for the program in order to run the calculation.

Once all parameters have been set, it is possible to run once more the simulations, just as before while analyzing the current building's situation. In order to achieve a better understanding to the improvements, both results were compared in the same graphic.

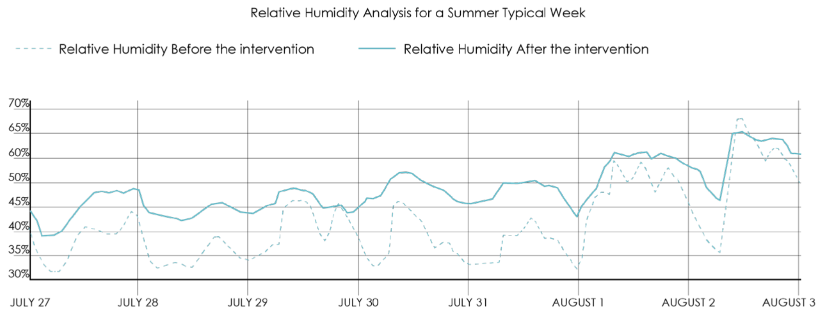
Typical summer week results

With the implementation of green walls in the surroundings of the buildings, it is possible to take advantage of the climatic conditions, to open up the building, as the vegetation acts like a shade to direct sunlight, allowing the sun light to enter while diffusing it, avoiding it to heat the internal areas. Vegetation integration to the façade also aids to reduce the internal temperature of the building, as plants reduce outdoor temperatures into a maximum of three degrees, by creating a clean source of oxygen and humidity. As a result, the integration allows the building to receive natural ventilation of quality.



Graphic 17. Temperature analysis for a summer typical week

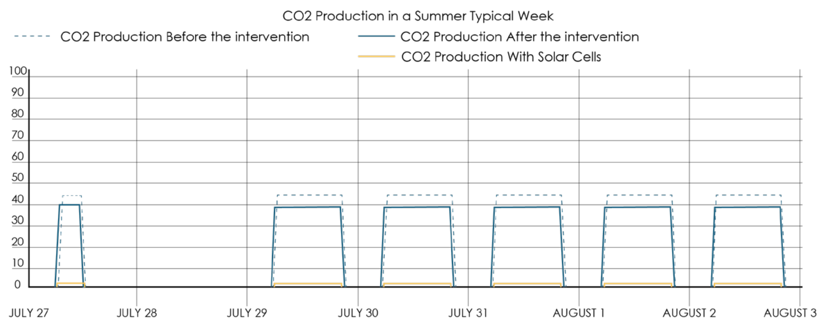
The results elaborated by the software are proof to the implementation of the theory. By placing the vegetation into the façade, the air temperature circulating through the building is even fresher than the external temperature, keeping the internal building's temperature quite similar to the outdoor temperature. The difference of temperature from the original project is significant, even to the point of reducing the necessity to implement cooling equipment during the warmest weeks of summer.



Graphic 18. Relative humidity analysis for a summer typical week

Another feature that comes with the application of vegetation all around the structure is the rising of the internal humidity levels. There is an average difference of 10% regarding the original's project internal humidity levels, and is it also strictly related to the external conditions of the area. Therefore, if it rains, the humidity levels will considerably rise and be maintained due to the enclosure created by the vegetation. This is an important factor to consider while choosing materials and the specific type of plants to be placed in the project.

In other aspects, due to the increment of the natural light and ventilation, the use of bulbs and cooling equipment during the working hours is less necessary. As a result, the energetic expenses and Co2 production reduces, as shown in the following graph:



Graphic 18. CO2 production in a summer typical week

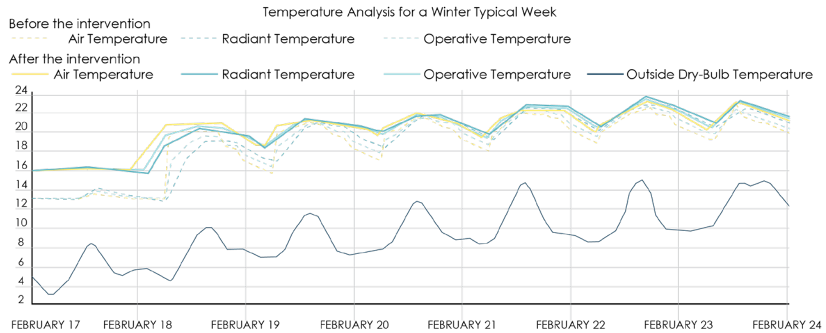
The graphic does show a huge difference, because of the activity developed in the building. It seemed interesting to run the CO2 simulation also without the use of the solar cells, in order to have a better understanding of how the most single features might change the behavior of a building. Also, being an educational structure, it was calculated with the bigger expenses scenario, in other words, a scenario in which essential lights are always on during working hours, and some cooling devices as well. The emissions for any equipment such as computers, kitchen, elevators, and so on, are also included in the calculation. On the other hand, with the implementation of the solar cells into the simulation, the building achieves the Near to Zero standards, as the energy produced by the solar cells is more than enough to cover the building's requirements for energy.

Typical winter week results

Same simulations were ran for the situation during winter, revealing also some improvements. In the same way, because of the integration of vegetation into the facades, and the addition of Solar Cells into the new glazing of the building, also in this time of the year it has an important influence to the internal building's temperature and illumination. The vegetation aids to maintain the internal temperatures, working as an isolating layer to the building while natural ventilation is not allowed.

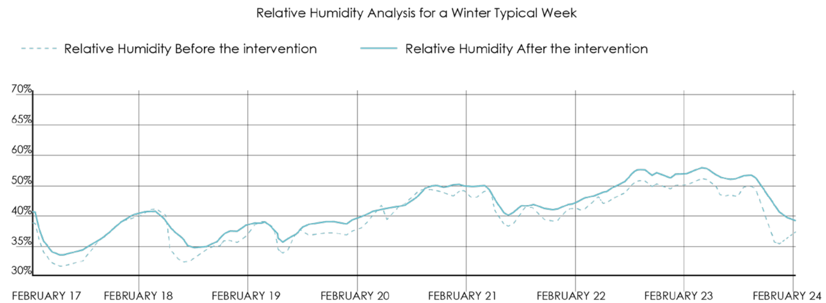
At the same time, the new facades design consent the access of more sun light into the building, improving not only the quality of life inside the structure but also

helping to rise and maintain the required temperatures for winter in internal areas. As a result, even if the internal temperature is not so different, as higher temperatures might also be too warm for the users comfort, the two features reduce the heat loses of the building, lowering the expenses of heating equipment.



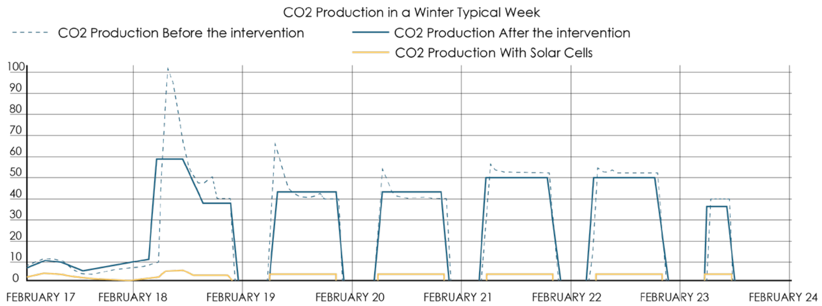
Graphic 19. Temperature analysis for a winter typical week

While in winter, plants remain only as an external feature, therefore the internal relative humidity does not change significantly.



Graphic 20. Relative humidity analysis for a winter typical week

On the other hand, for the Co2 production of the building, as the new features help to maintain a more constant condition for the internal areas, the elevated peaks in the Co2 production are significantly reduced. Therefore, it was calculated also for this analysis the building's behavior without the features of the solar cells. On the other hand, with the use of the energy produced by the solar cells, the emissions are reduced significantly, as it is expected, into achieving the Near to Zero standards.



Graphic 21. CO2 production in a winter typical week

The final project

8

8.1. The final project's plans

The project is no other than the realization of all the concepts, analysis, tests and simulations described previously. Therefore, the following sequence of plans illustrates the result of the intervention over the Giovanni Ruffini's High School.

The aim was not only to assist the structural deficiencies of the building, but also to enhance its architectural aesthetic, energy performance and comfort quality, as to improve the building's functionality with the addition of new stories and dynamics.

The result is an entire renovation of the facades, internal sensations and functionalities of the buildin, with the idea of also give the users an identity feeling regarding the building.

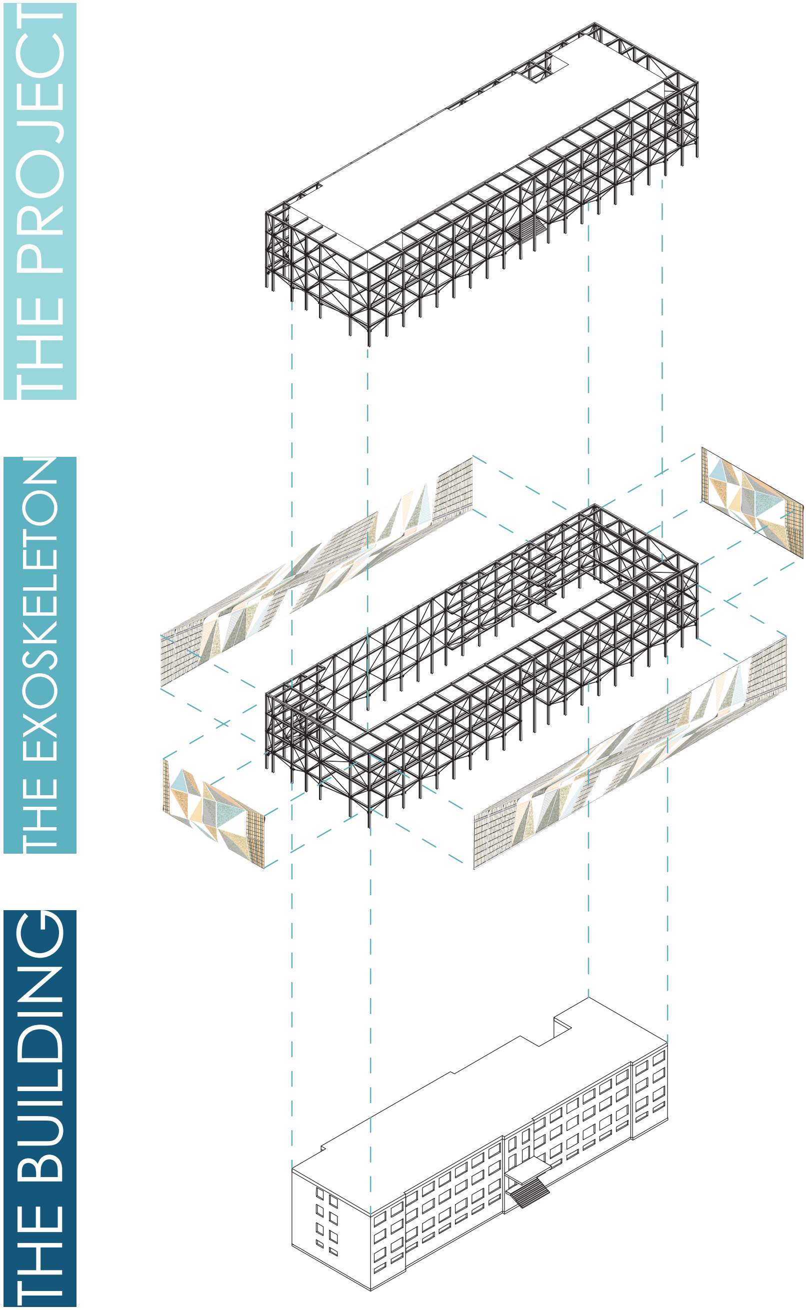


Figure 62. Axonometric Exploded view

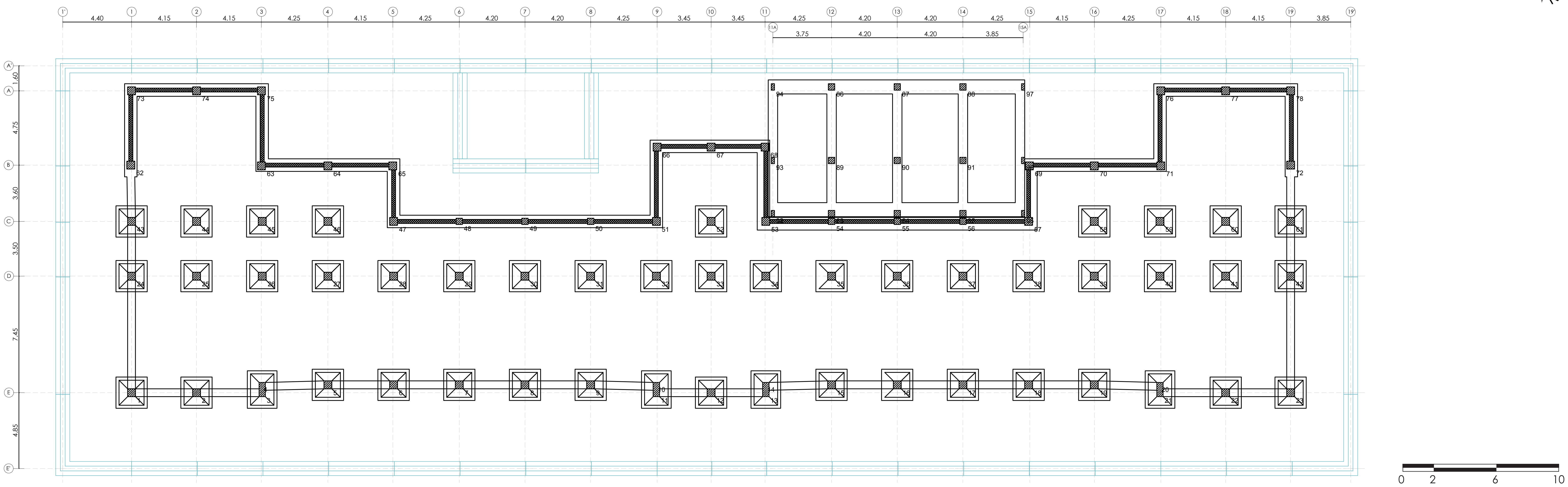
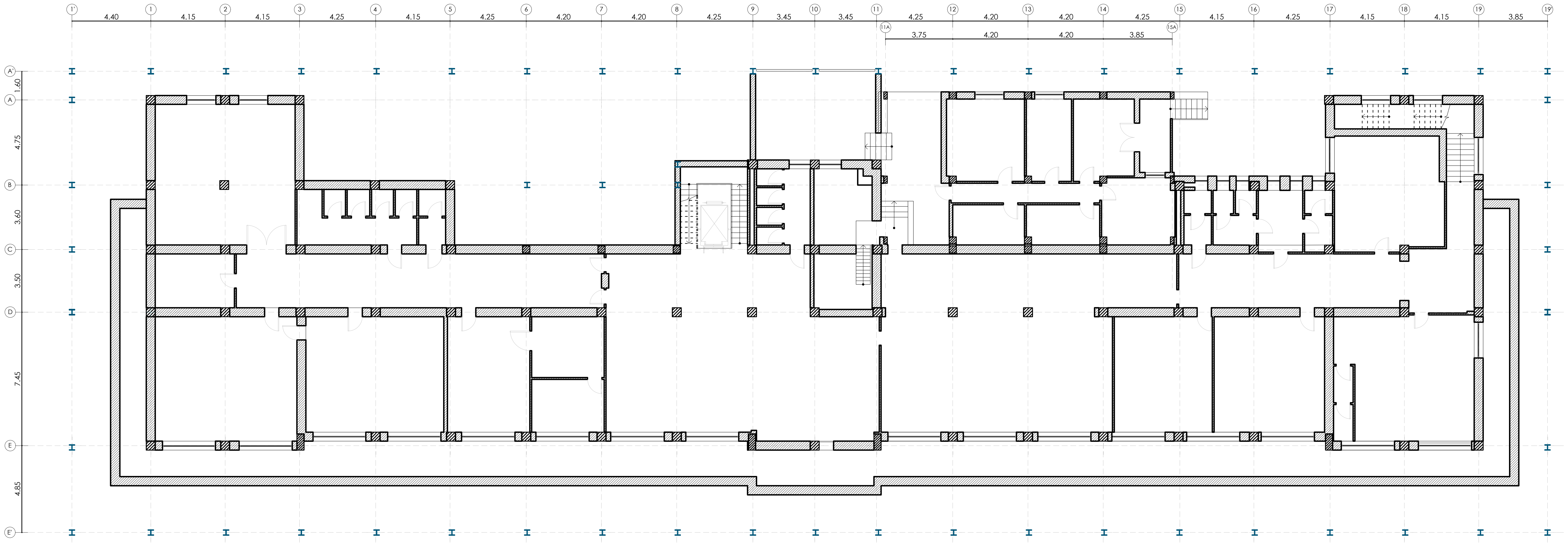


Figure 63. Foundation's Plan
Quote +/- 0,00 m | Scale 1:200



0 2 6 10

Figure 64. Basement Floor Plan
Quote + 3,60 m | Scale 1:200

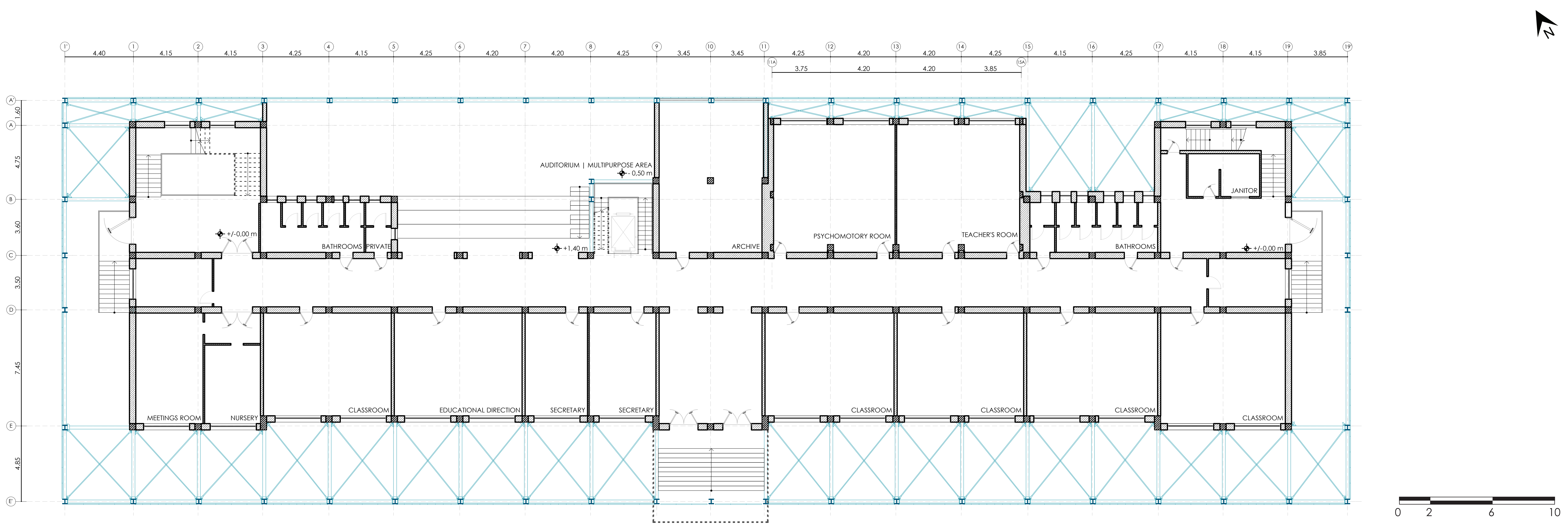


Figure 65. Ground Floor Plan
Quote + 7,43 m | Scale 1:200

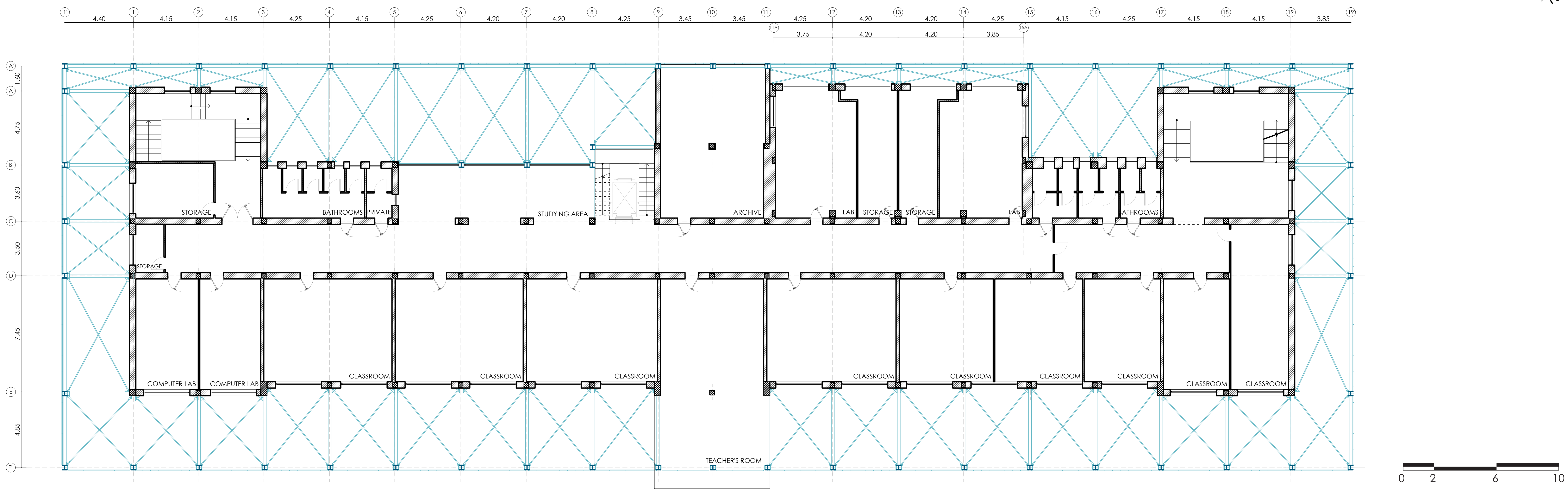


Figure 66. First Floor Plan
Quote +11,25 m | Scale 1:200

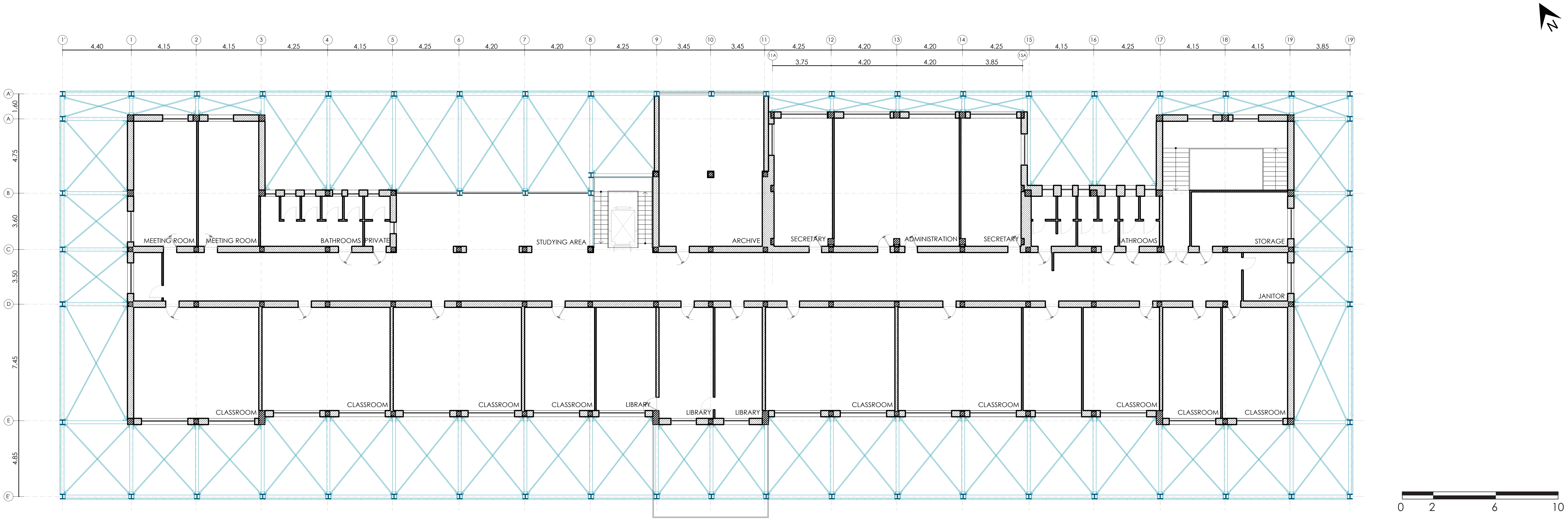


Figure 67. Second Floor Plan
Quote + 14,80 m | Scale 1:200

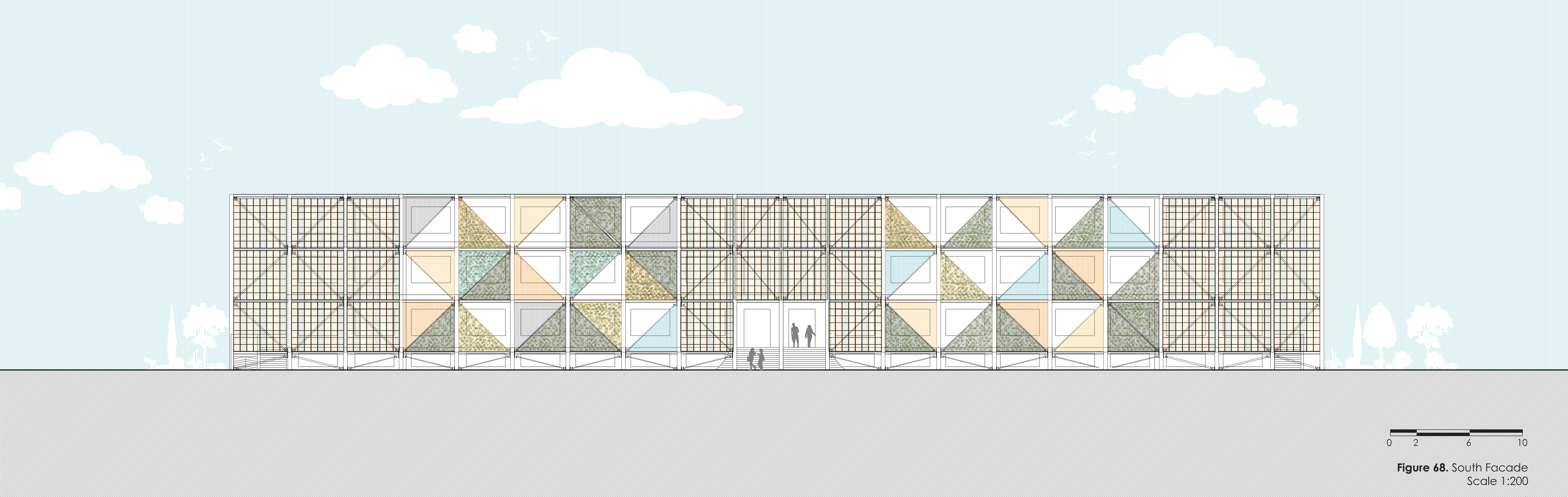


Figure 68. South Facade
Scale 1:200

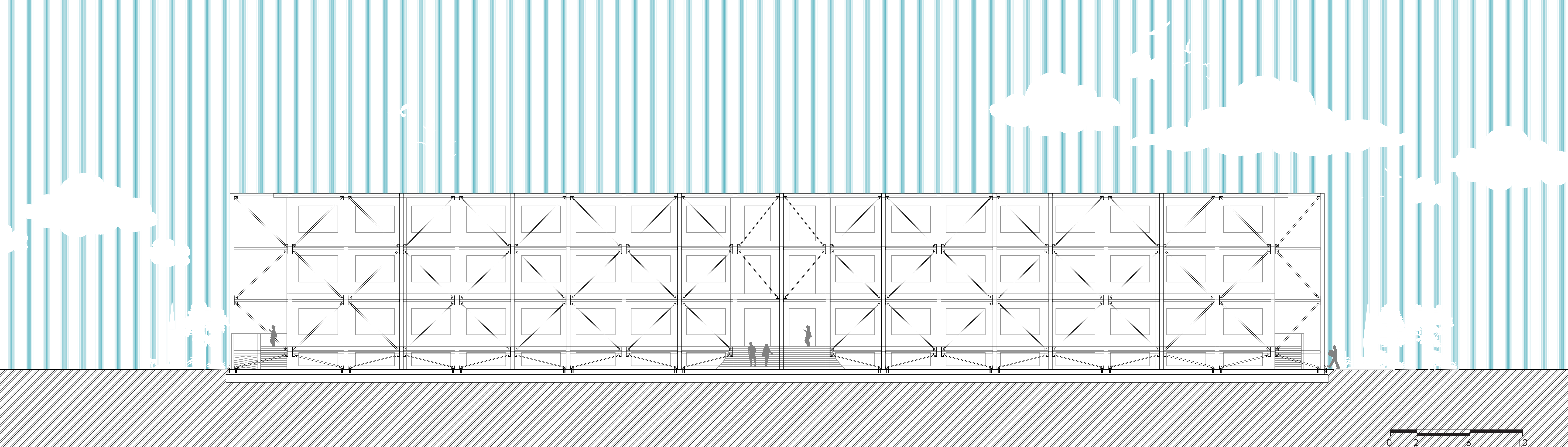


Figure 69. Exoskeleton South Facade
Scale 1:200

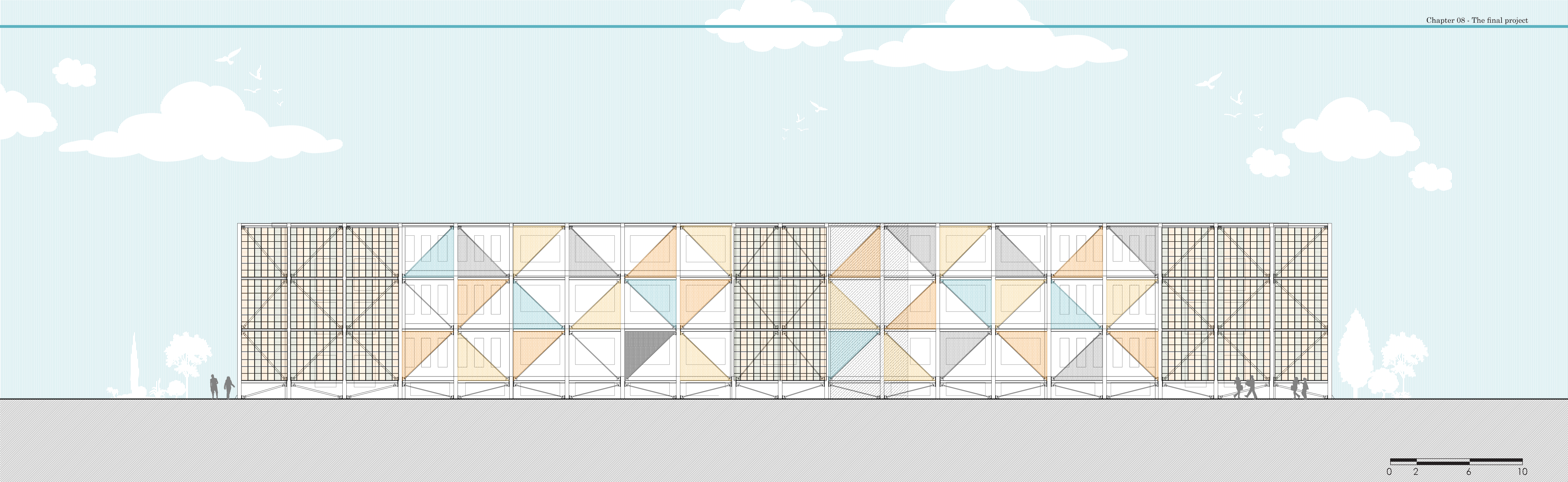


Figure 70. North Facade
Scale 1:200

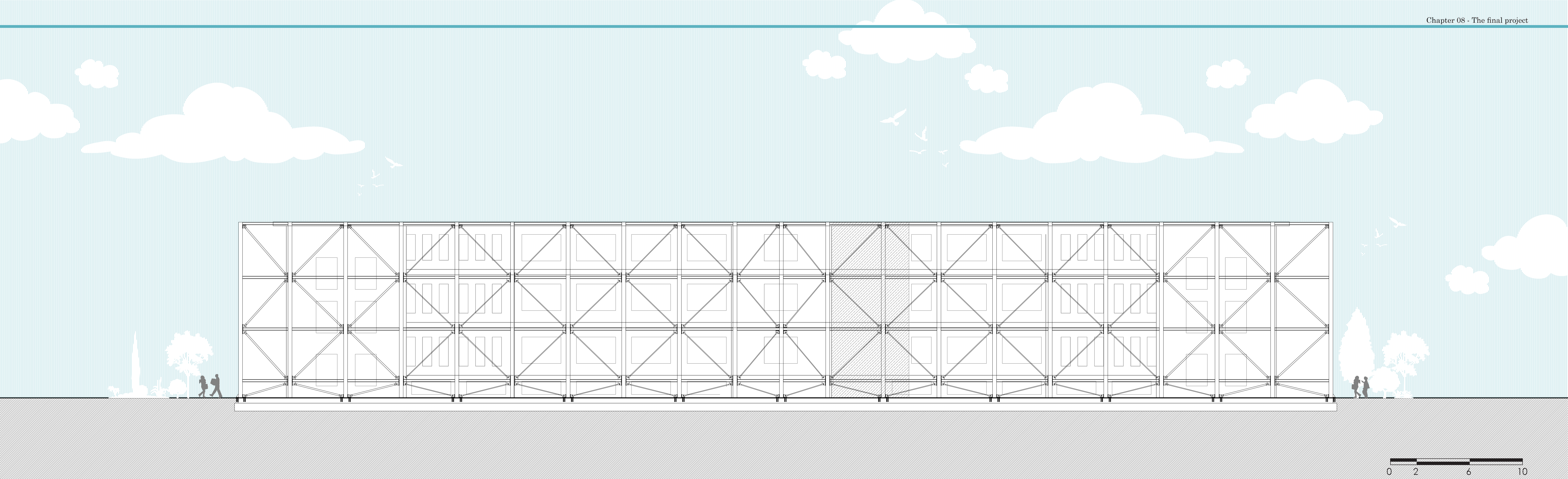


Figure 71. Exoskeleton North Facade
Scale 1:200

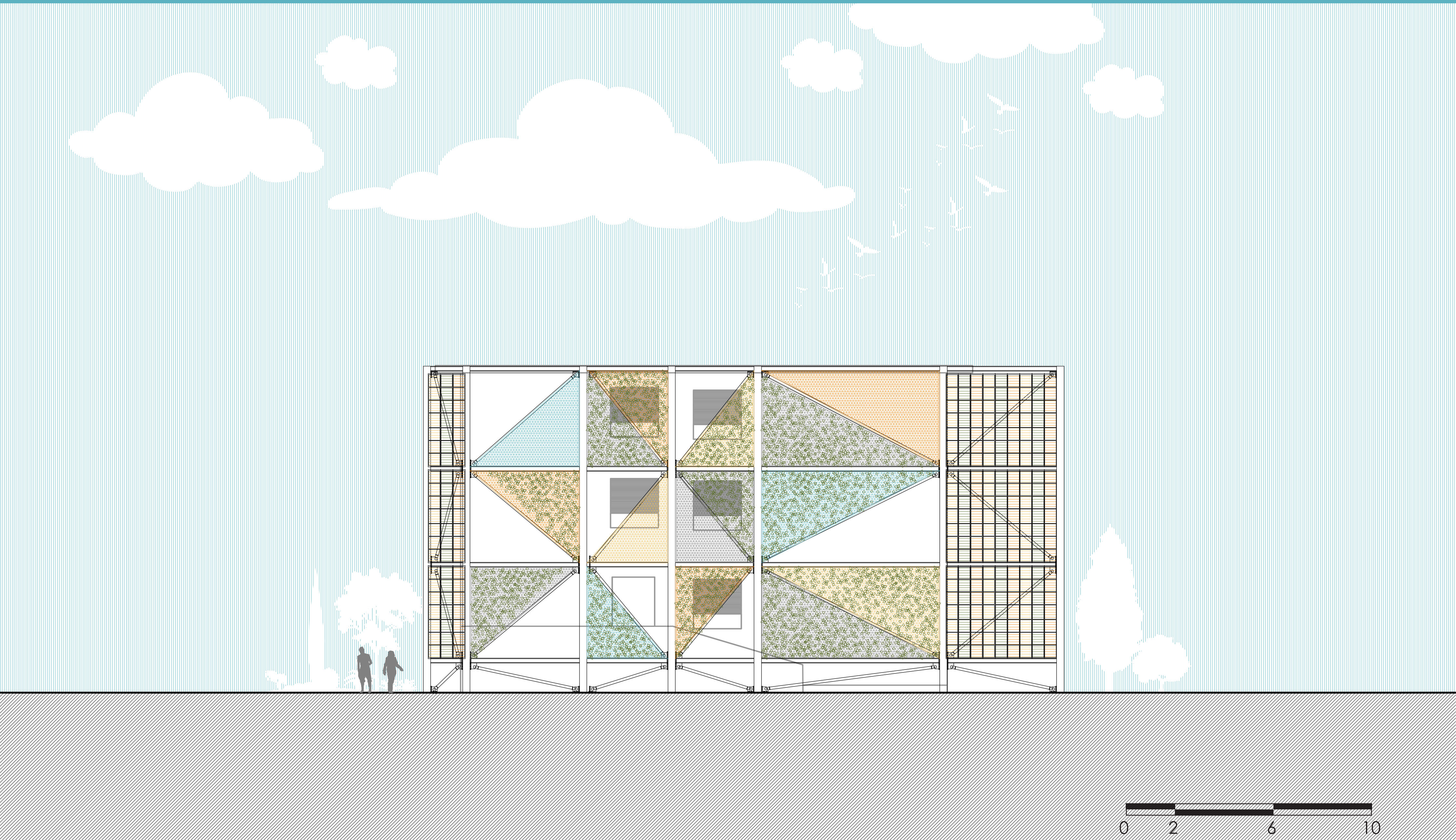


Figure 72. West Facade
Scale 1:200

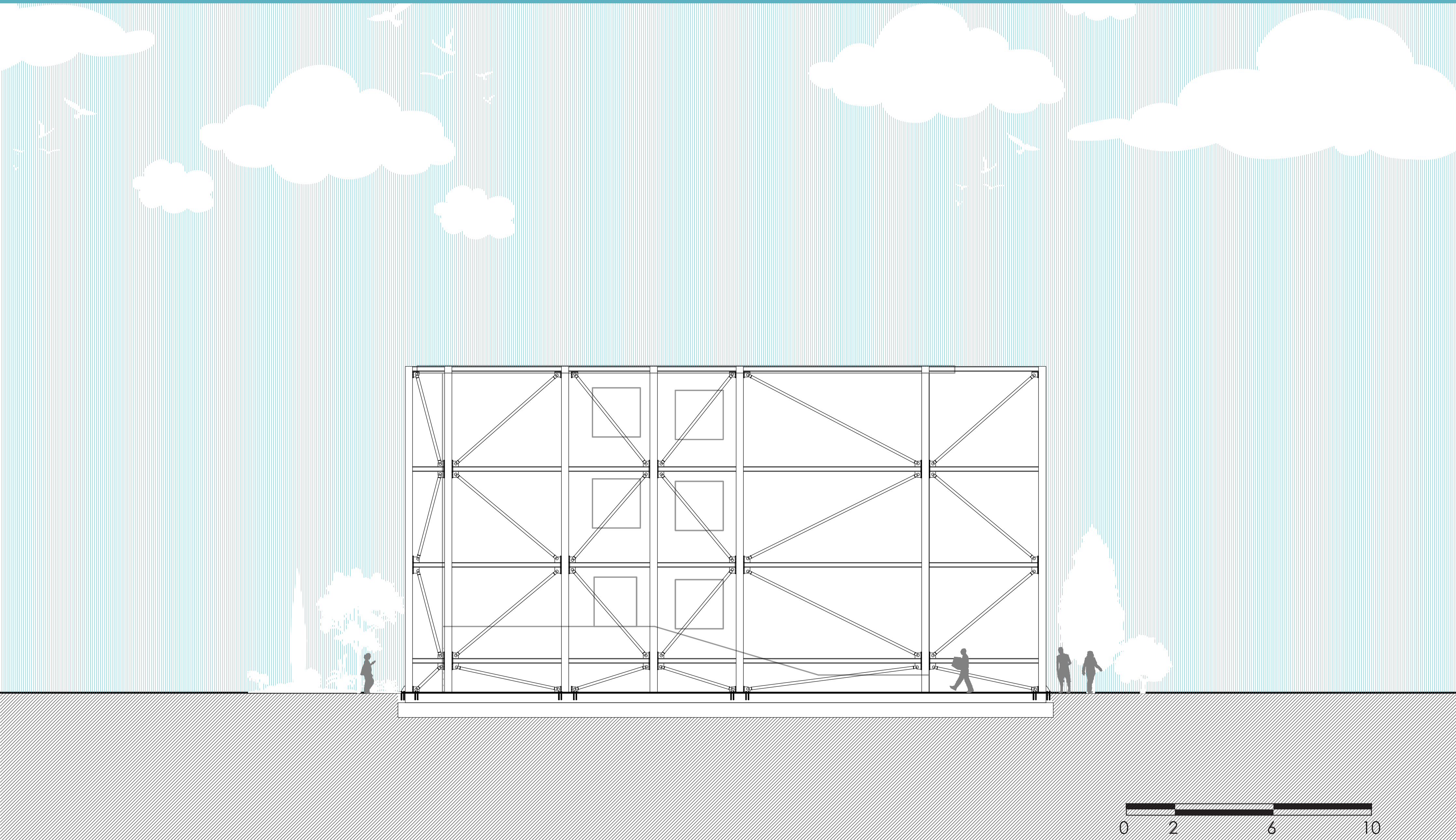


Figure 73. West Facade Exoskeleton
Scale 1:200

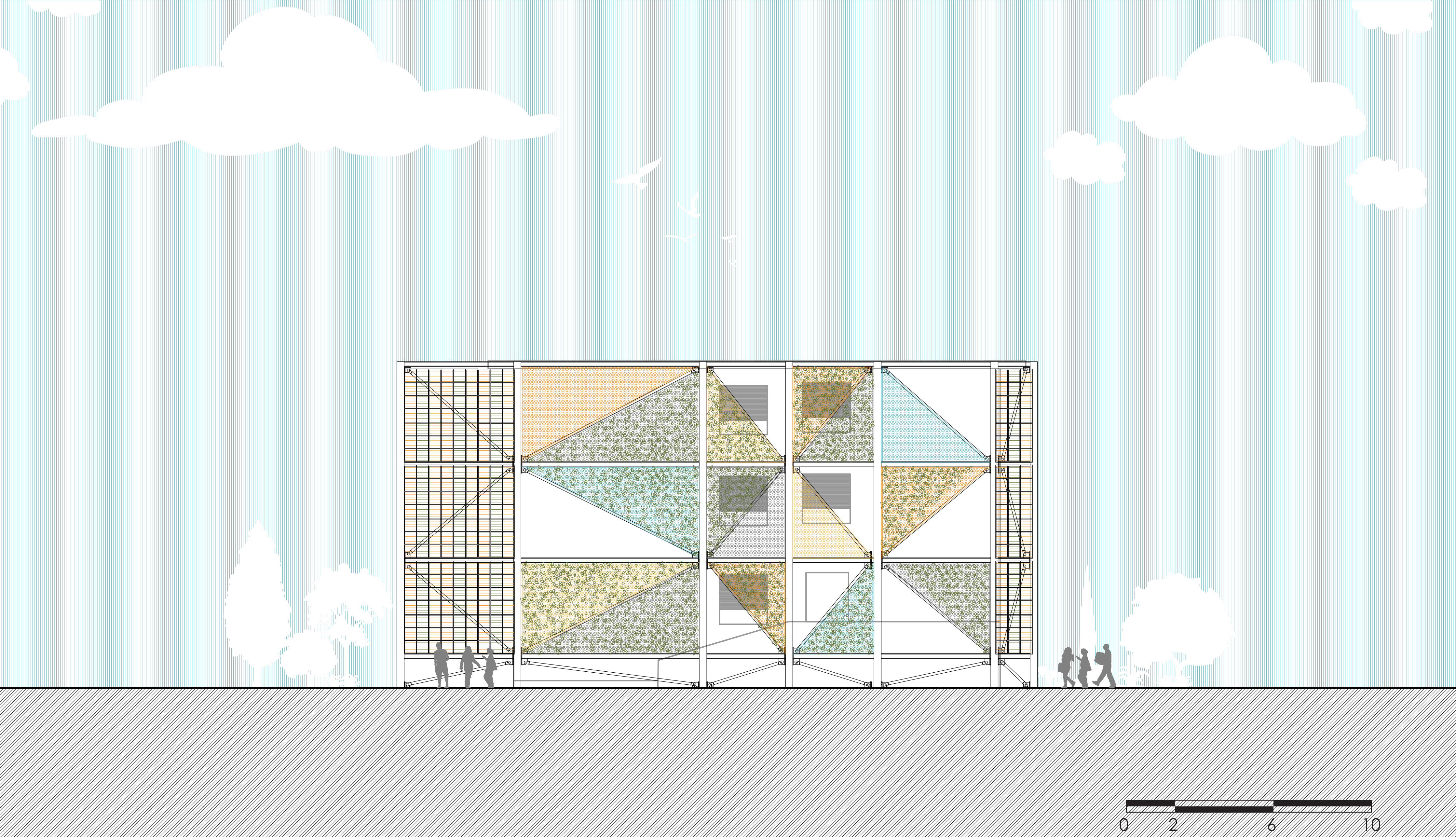


Figure 74. East Facade
Scale 1:200

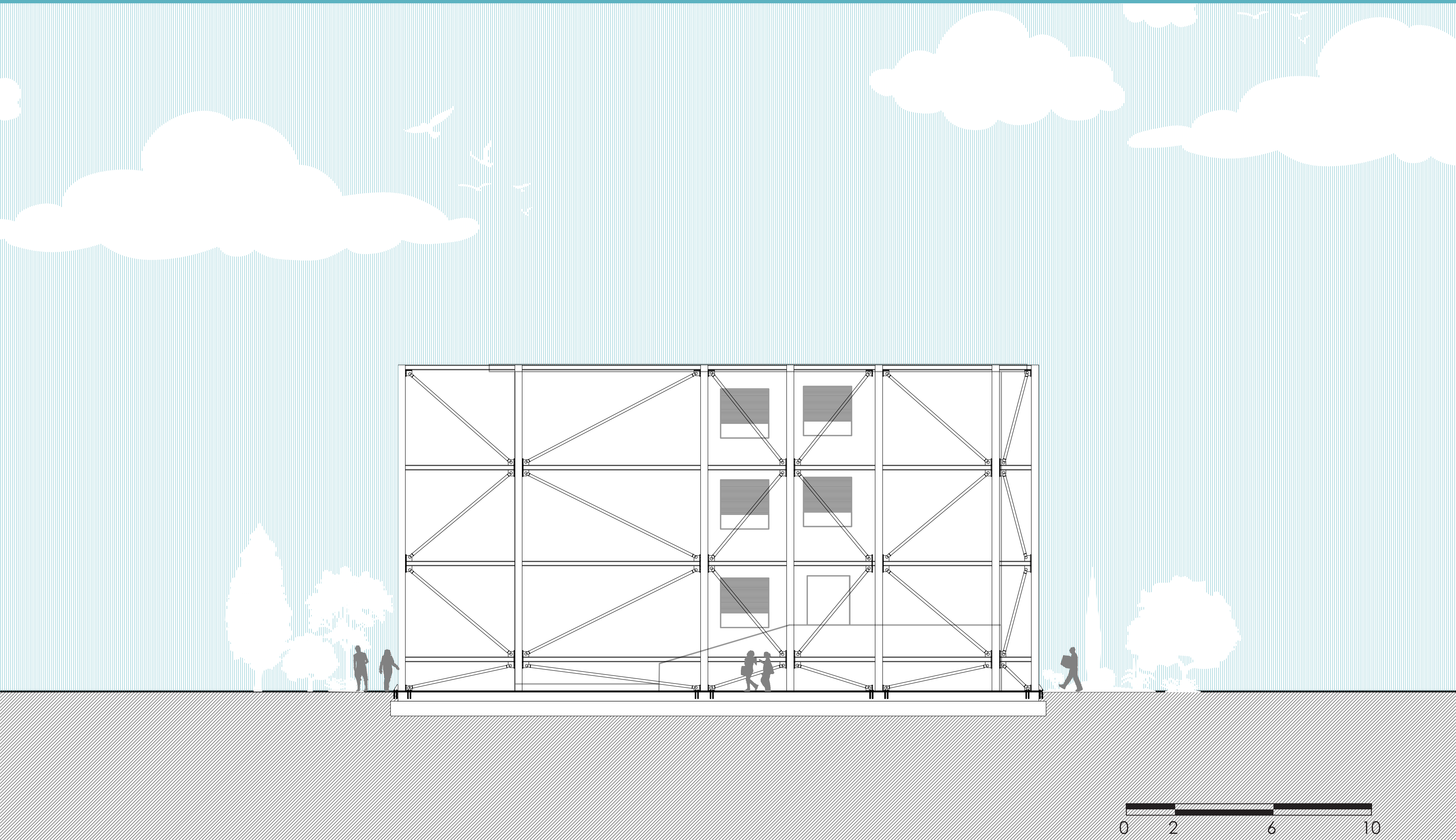


Figure 75. East Facade Exoskeleton
Scale 1:200

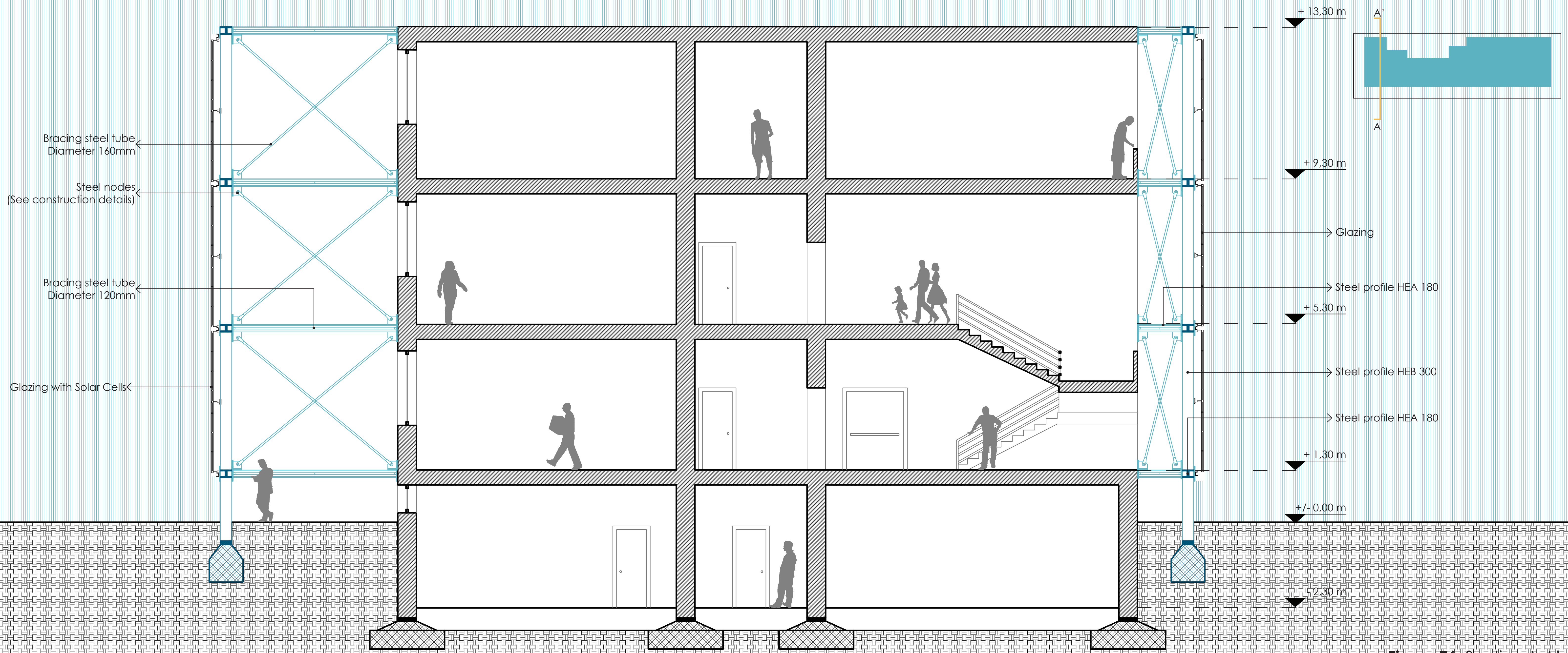


Figure 76. Section A-A'
Scale 1:100

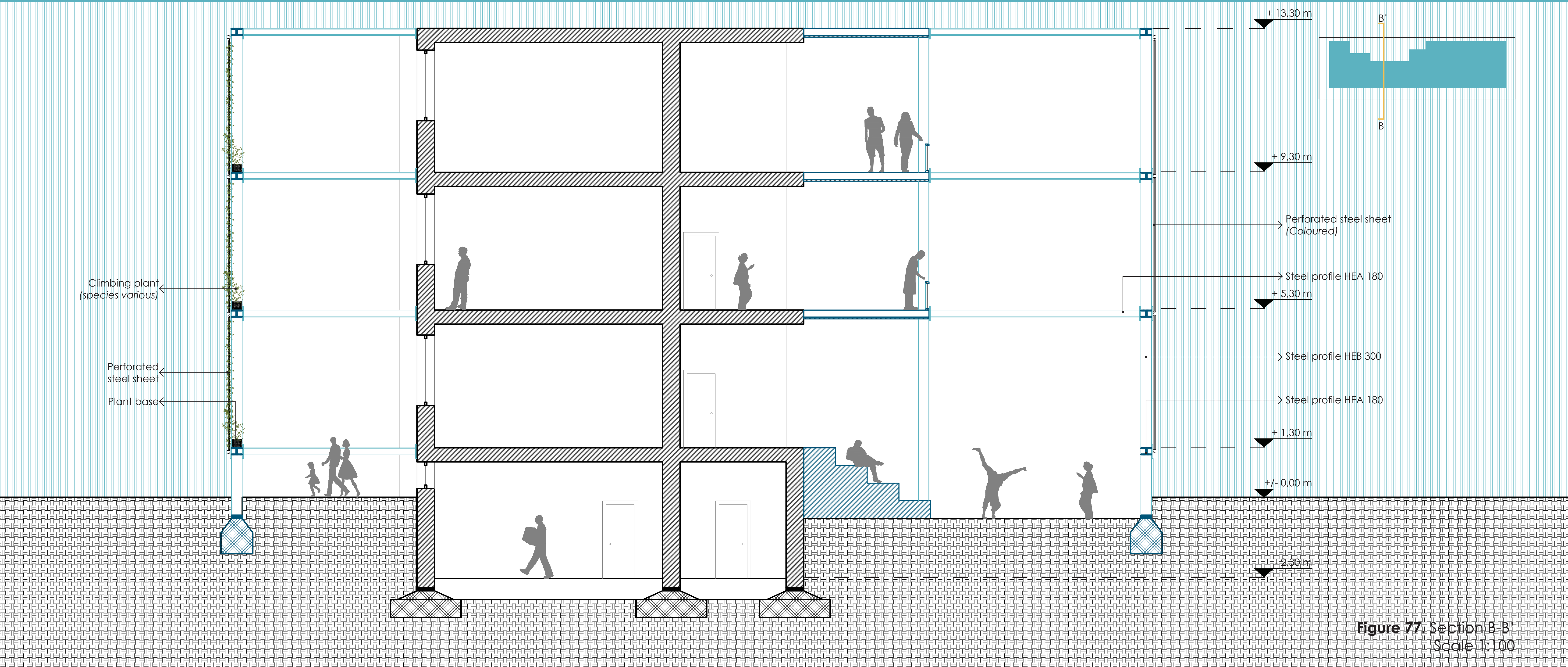


Figure 77. Section B-B'
Scale 1:100

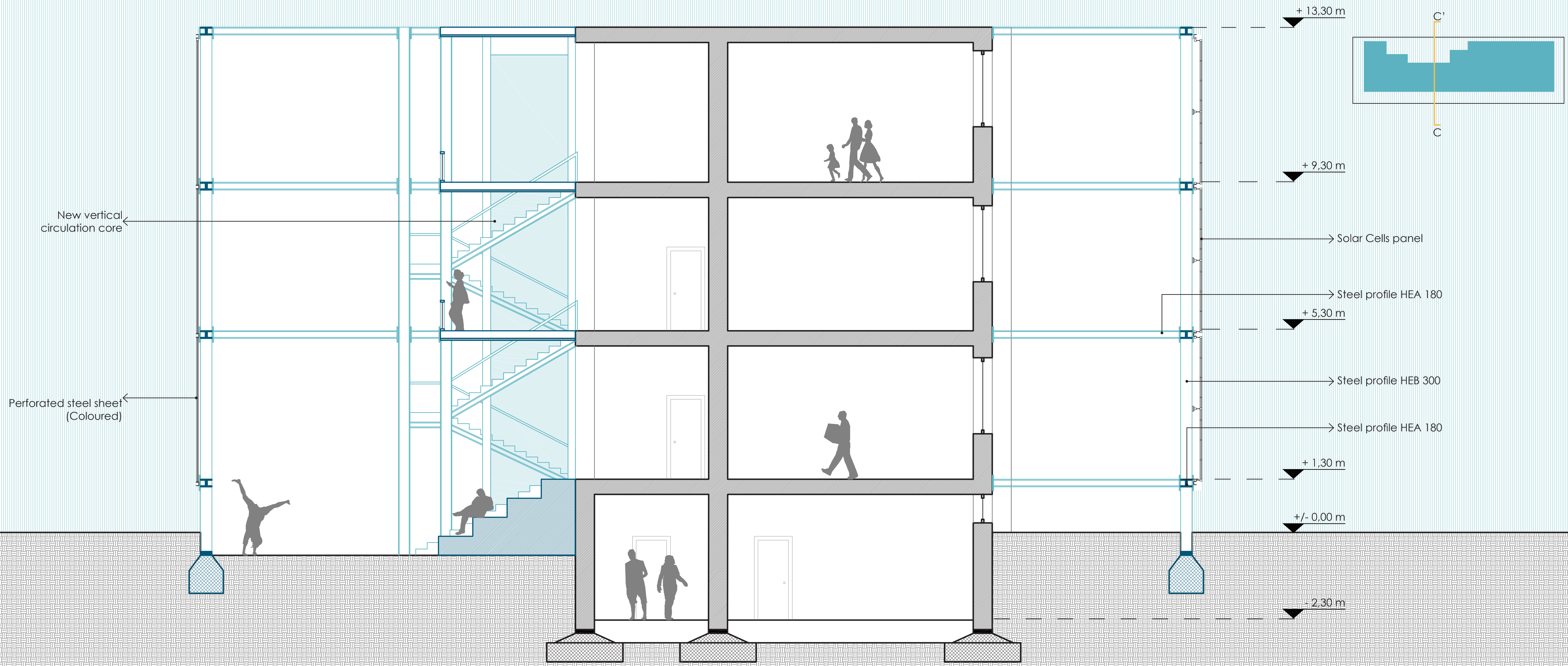


Figure 78. Section C-C'
Scale 1:100

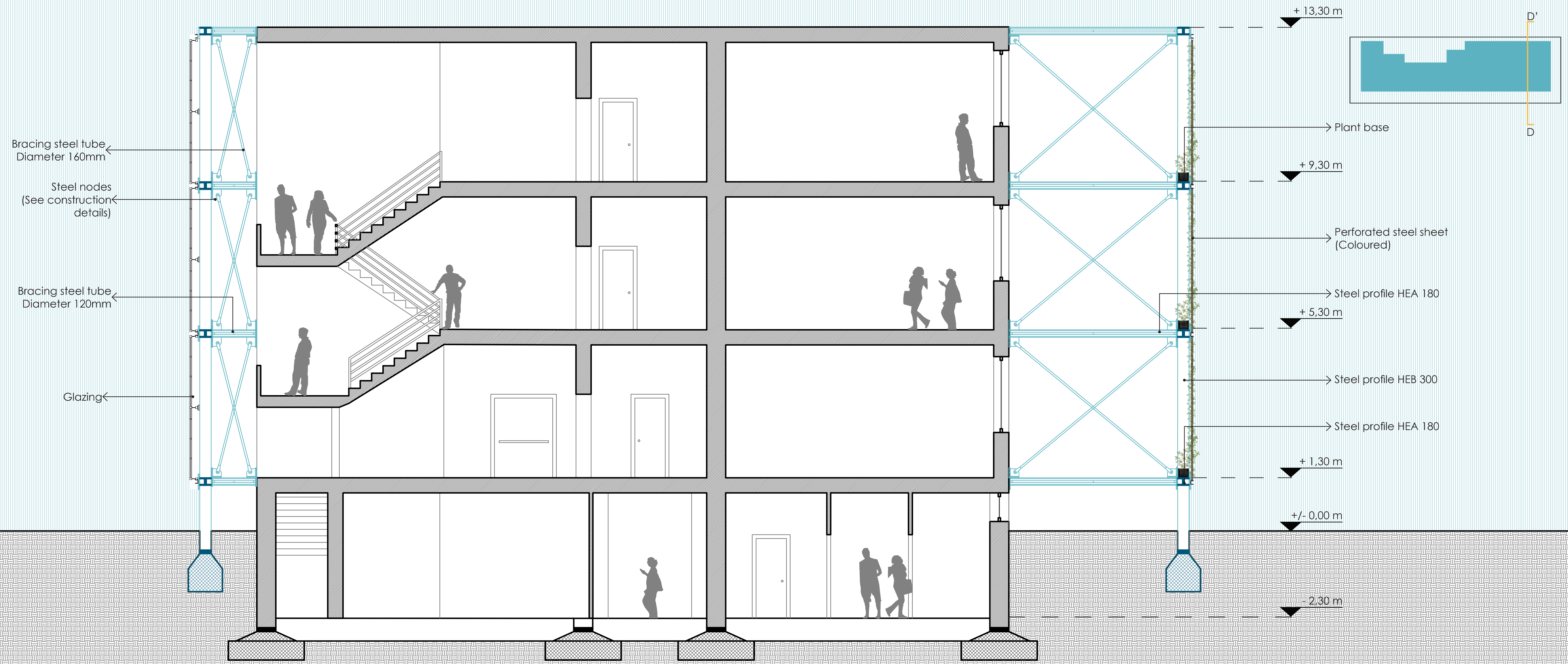


Figure 79. Section D-D'
Scale 1:100

Figure 80. Internal View

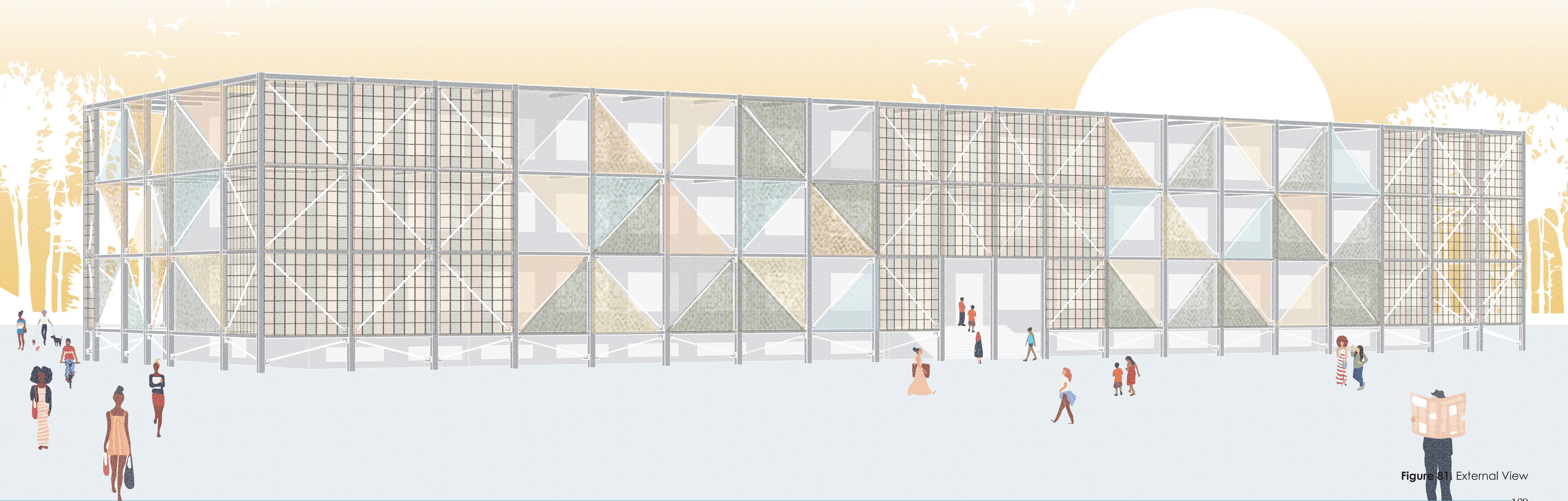


Figure 81. External View

8.2. Construction details of the exoskeleton

The following part illustrates the details for the assemble of the exoskeleton, all the nodes specifications, from the materials to the section of each tube.

It is important to remember, as explained before, the nodes are the most important part of the exoskeleton's structure, as the bracings are the elements that give the structure the stiffness, flexibility and force movements that is needed in order to enhance the existent structure and convert it into a seismic resistant structure.

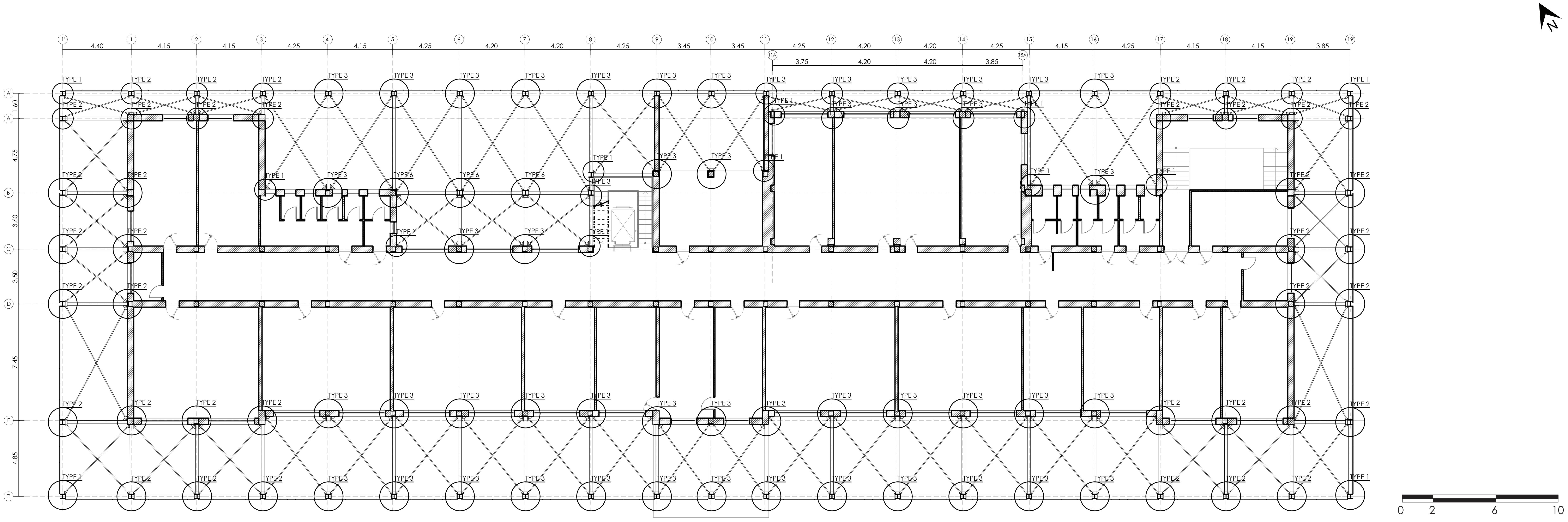


Figure 82. Typical Floor Plan Navigator
Typology of Connections | Scale 1:200

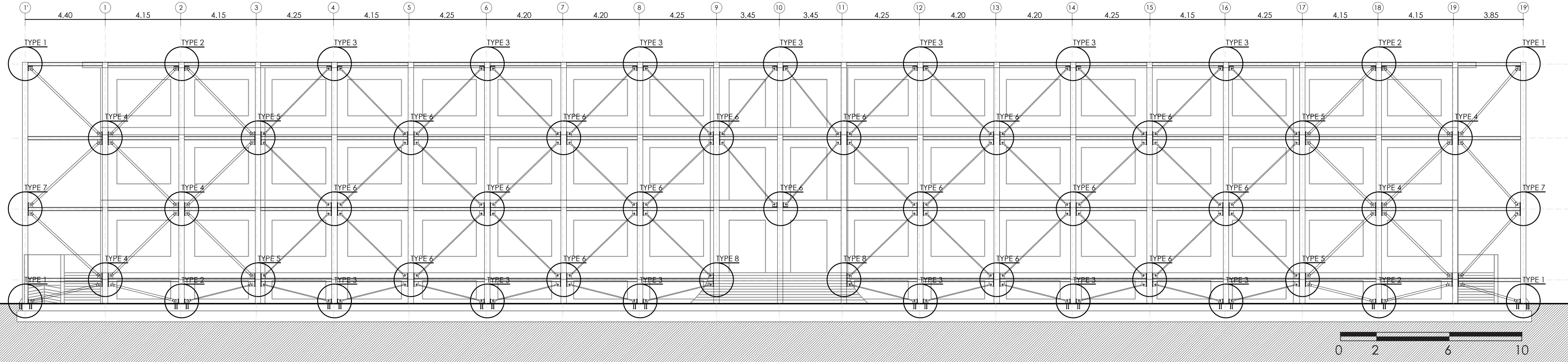


Figure 83. South Facade Construction Details Navigator
Typology of connections| Scale 1:200

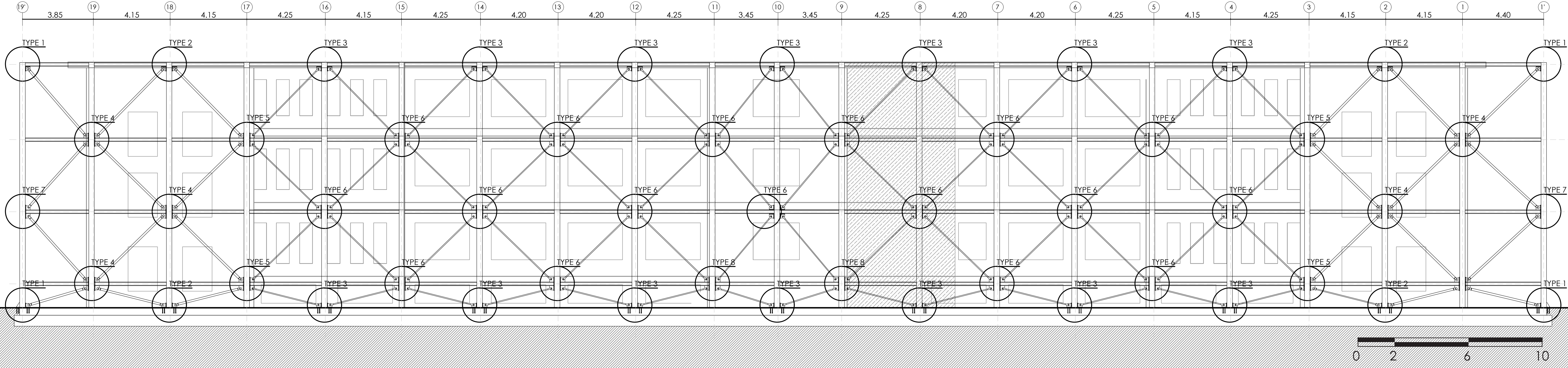


Figure 84. North Facade Construction Details Navigator
Typology of connections| Scale 1:200

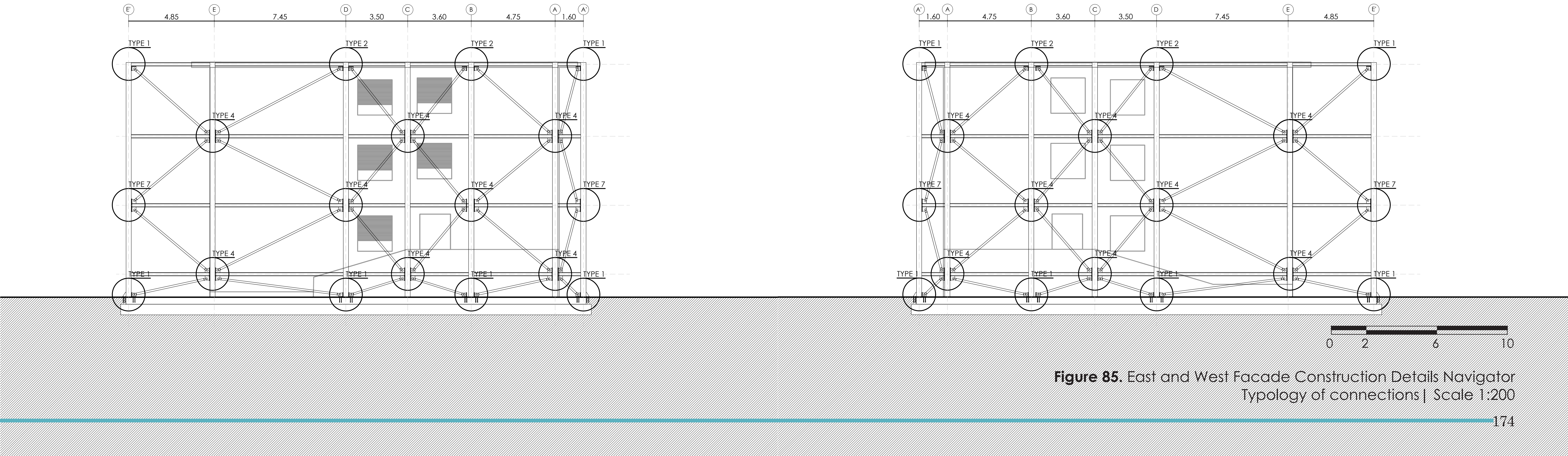


Figure 85. East and West Facade Construction Details Navigator
Typology of connections | Scale 1:200

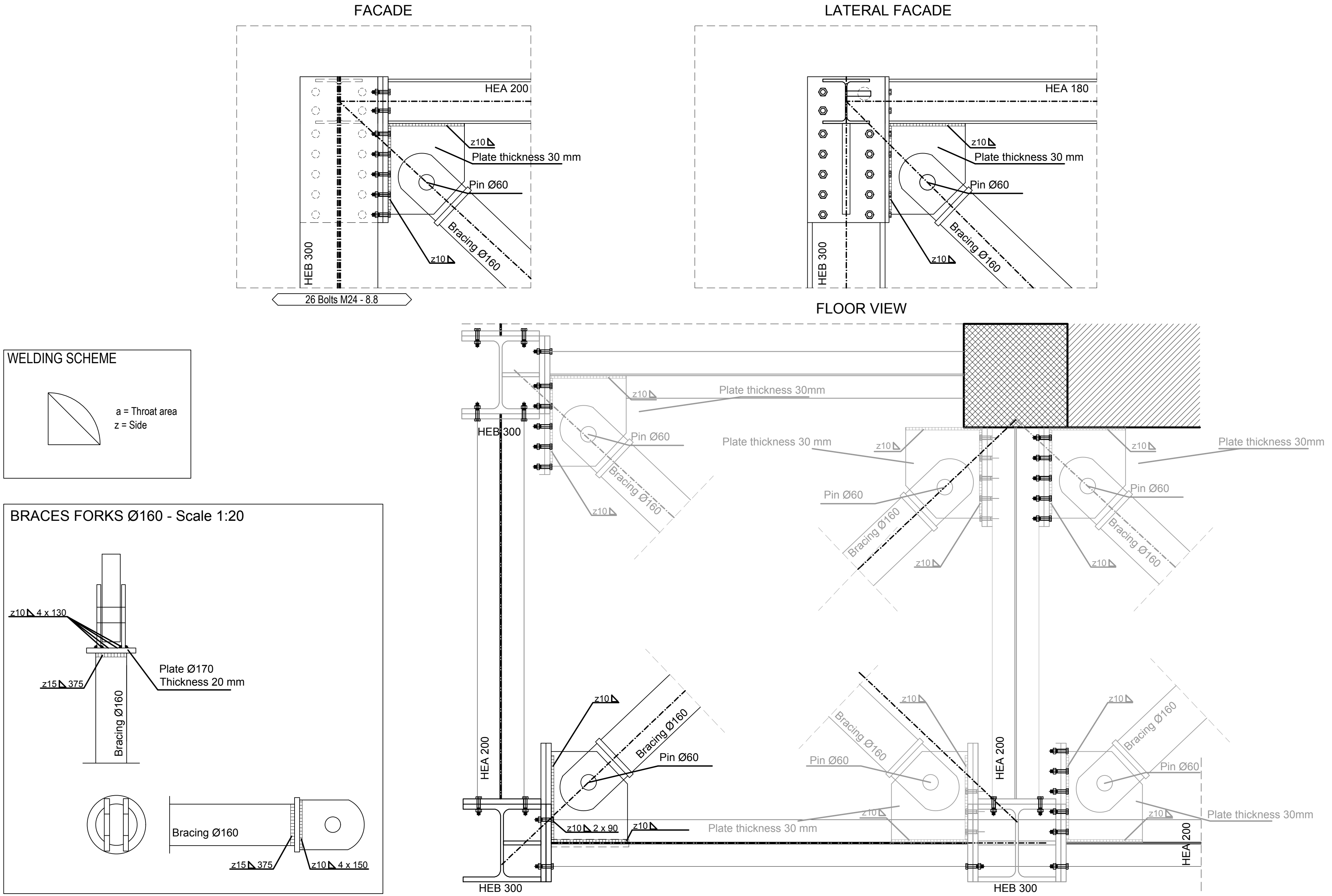


Figure 86. Connections type 1 | Scale 1:20

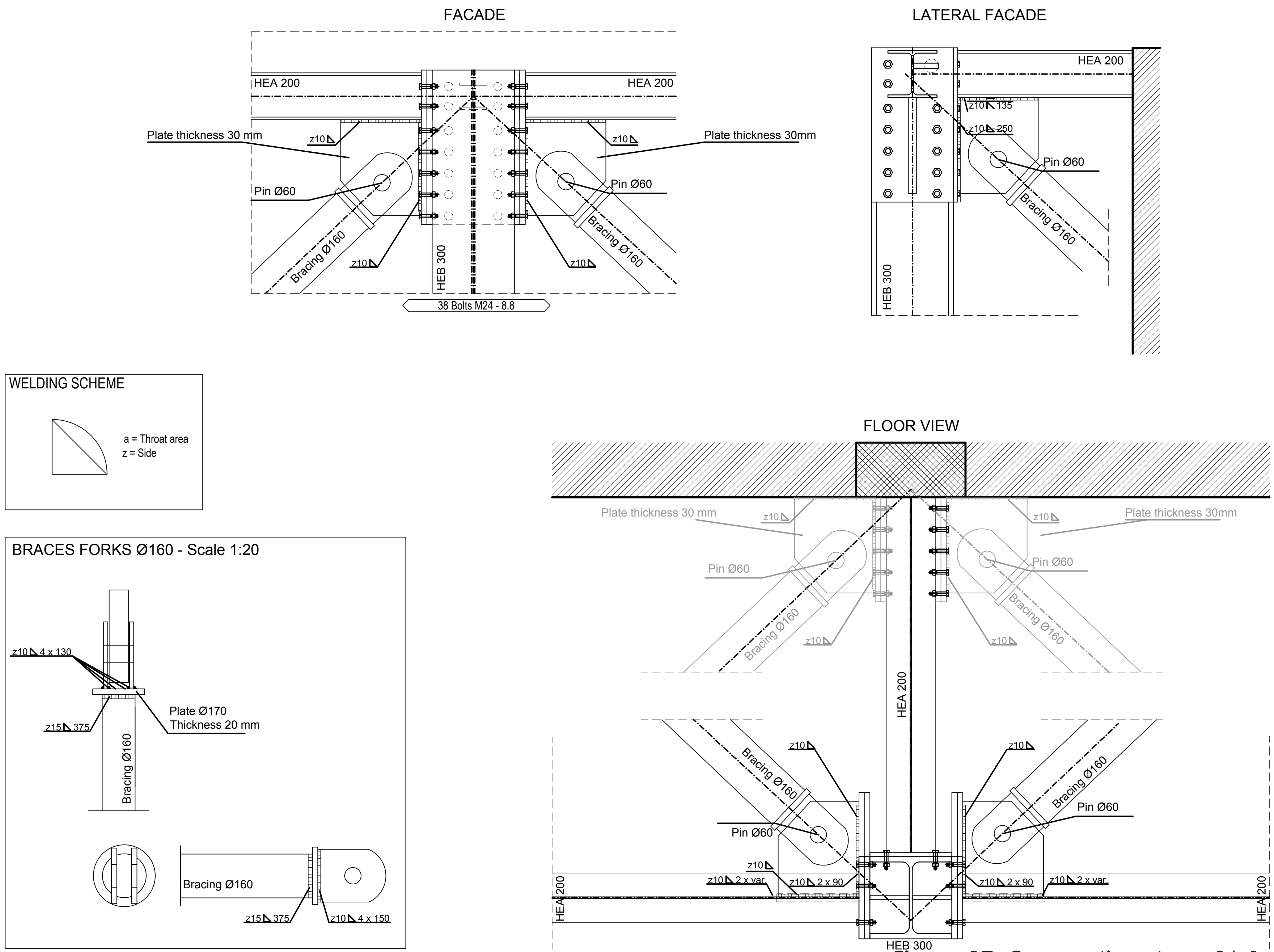


Figure 87. Connections type 2| Scale 1:20

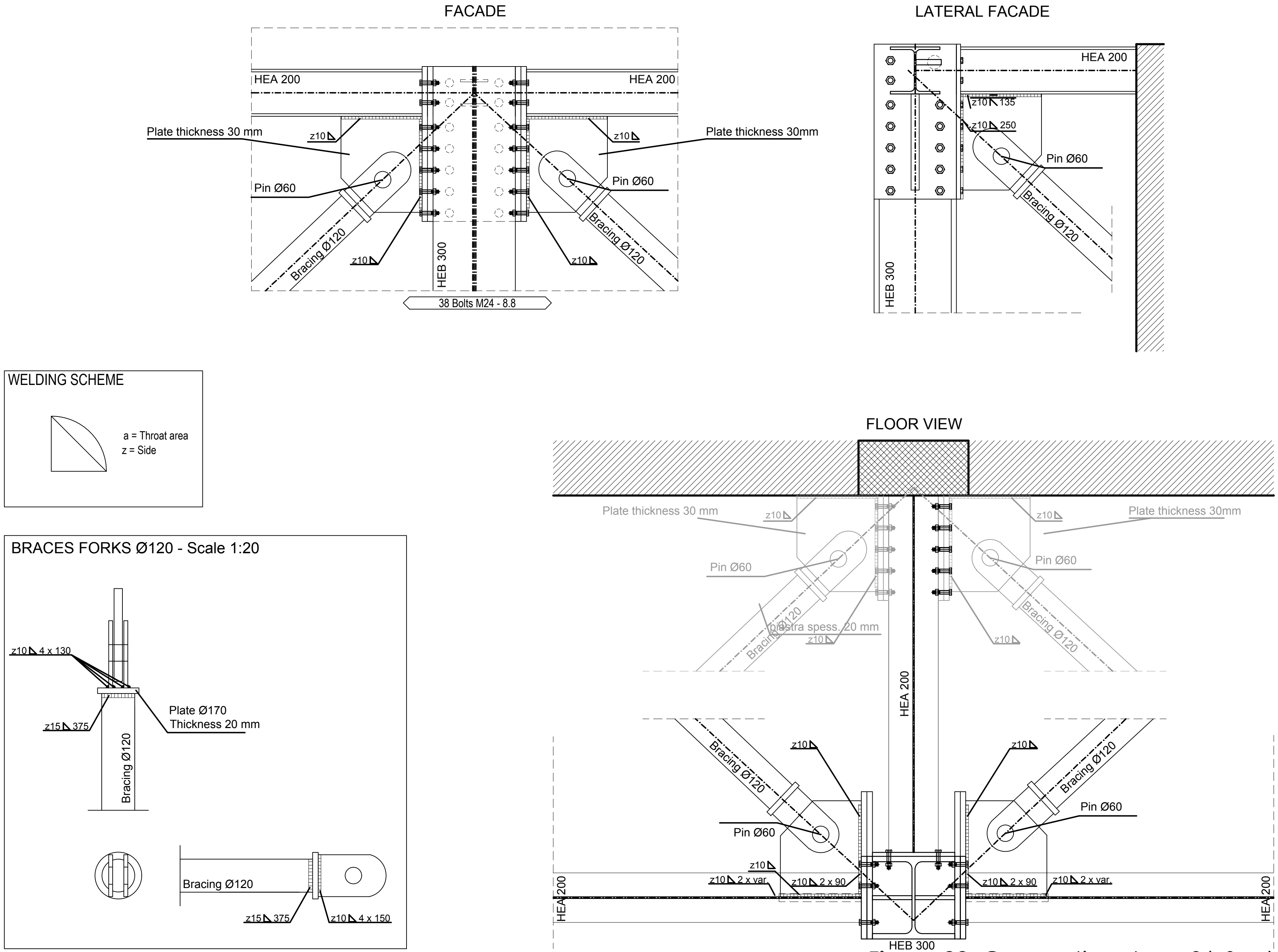


Figure 88. Connections type 3| Scale 1:20

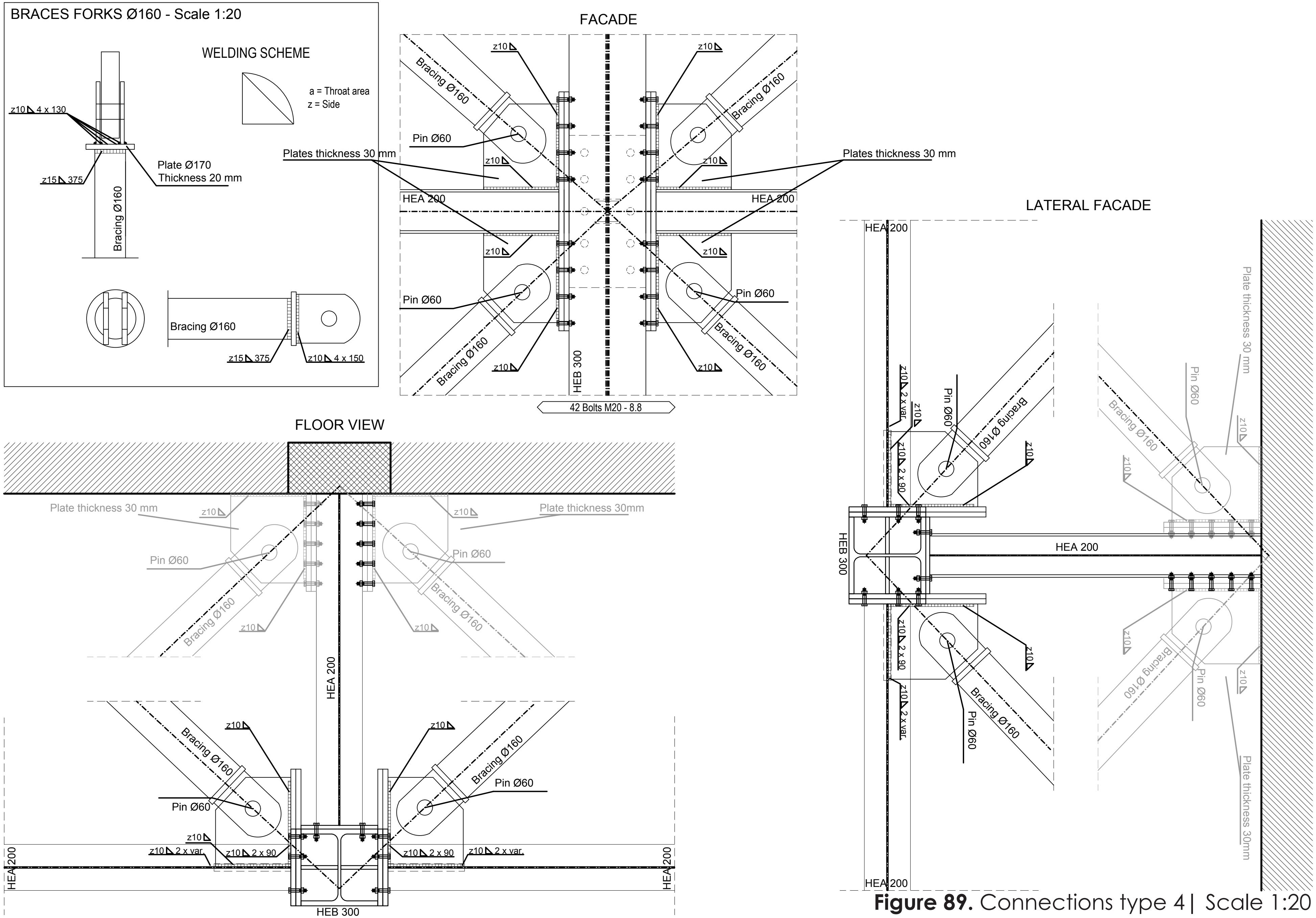


Figure 89. Connections type 4| Scale 1:20

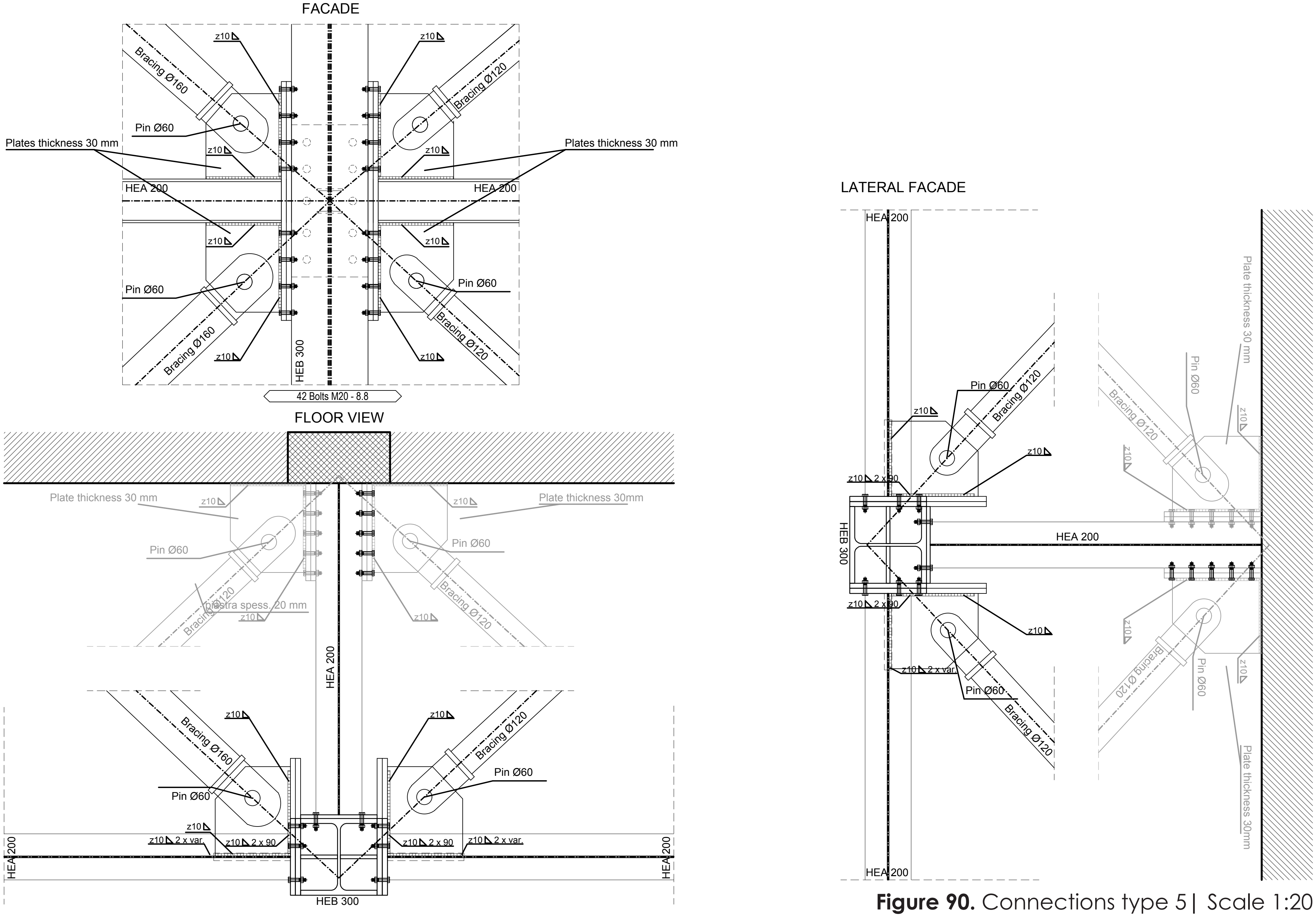


Figure 90. Connections type 5| Scale 1:20

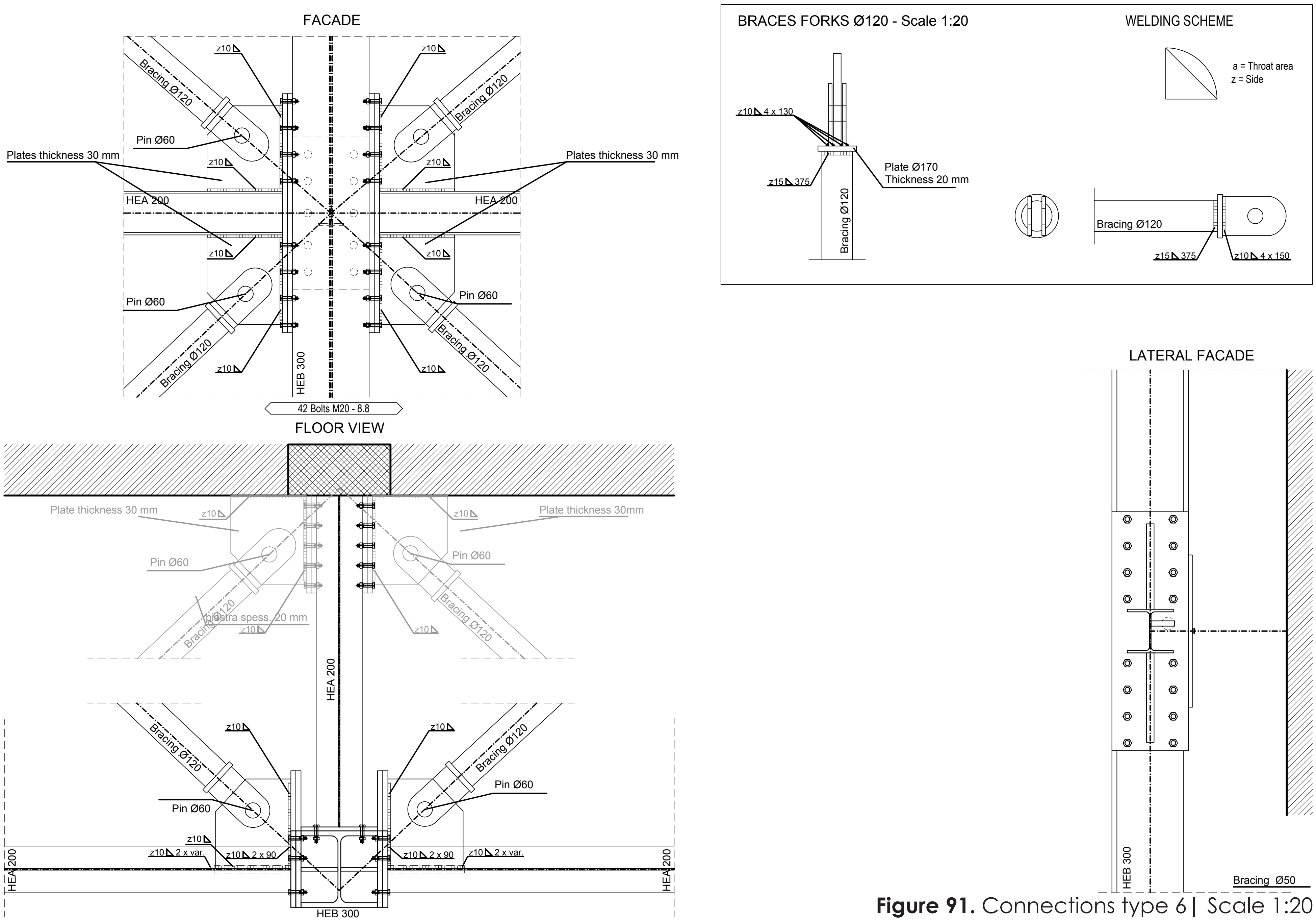


Figure 91. Connections type 6| Scale 1:20

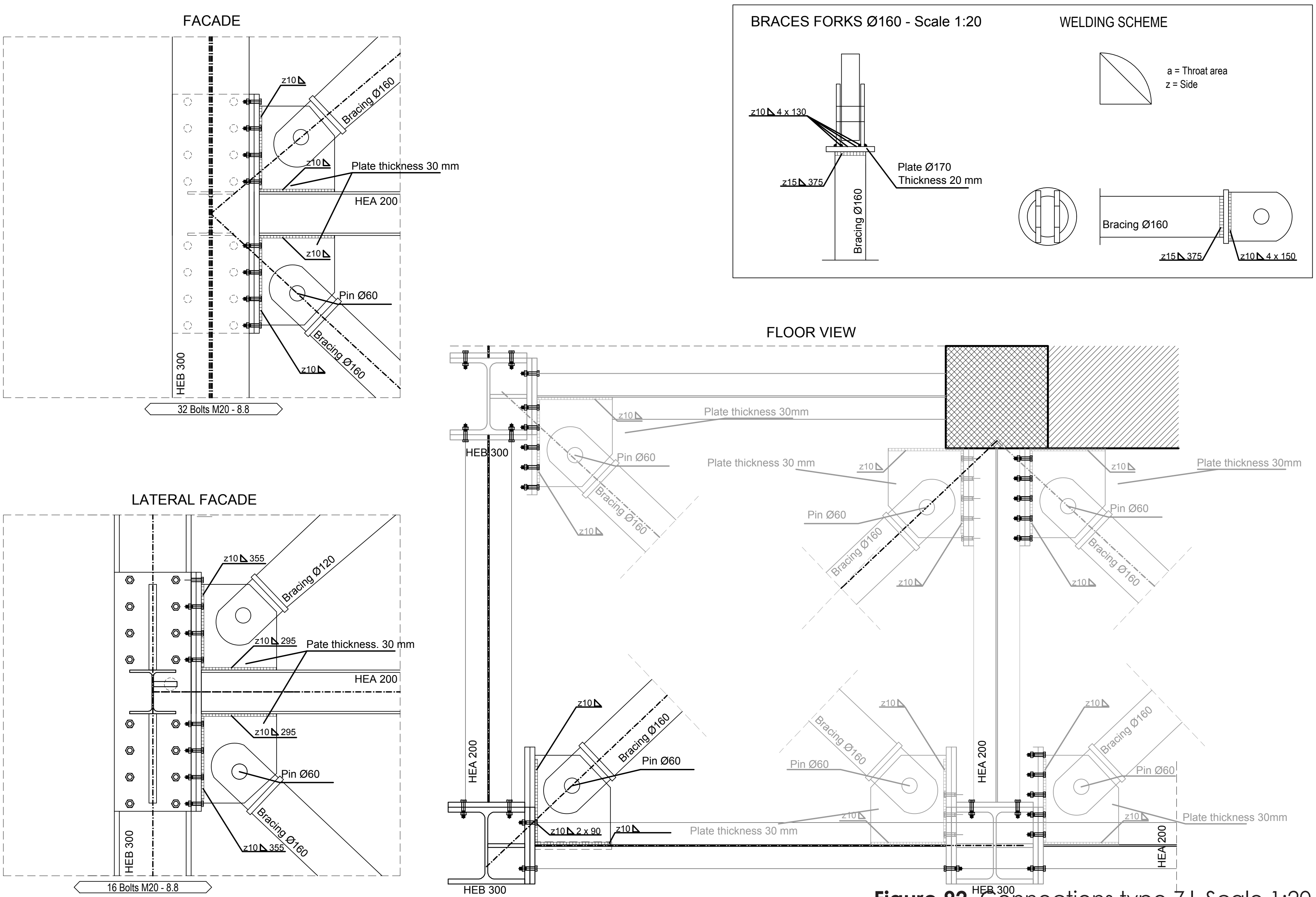


Figure 92. Connections type 7| Scale 1:20

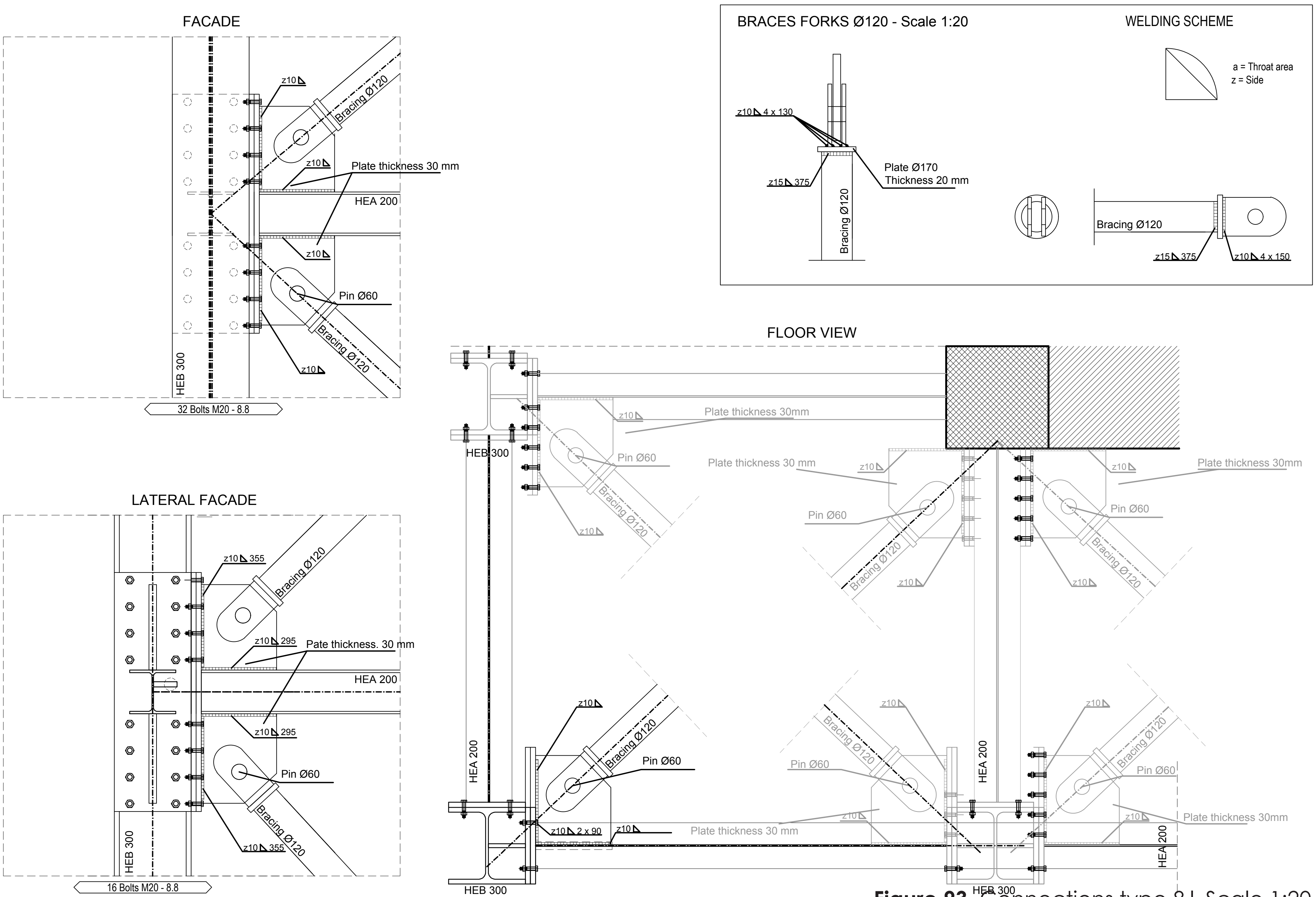


Figure 93. Connections type 8| Scale 1:20

9 Conclusions

9

Conclusions

Nowadays, the construction sector has shown to be not only the responsible of approximately 30% of the total wastes generated worldwide each year, but also for the largest amount of natural resources expenditure and carbon emissions.

The biggest issue was developed in Europe after the World War II because of the imminent housing demand, which caused a fast and low quality construction process. As a consequence there is and elevated number of existent buildings with a critical structural situation, decay, high energetic demand and an exhausted service life period. With such a big amount of buildings with this qualities, the possibility of demolition must be taken as a last resource, only for those structures which are impossible to recuperate. Demolition activities produce a huge amount of wastes, which will not decay or change over the years, unless they are transformed for recycling and just a small portion of construction wastes allow this process. There is also a significant amount of embodied energy stored inside the existent buildings, as natural resources consumption.

Therefore, the aim of this thesis was to present a different approach in order to solve the existent buildings' deficiencies in a more sustainable way, and to apply this proposal into an existing building in order to verify the feasibility of the solution. The project proposed the implementation of an exoskeleton to the original building's structure, and to integrate it with new technologies in order to also enhance the energy performance of the building and the comfort qualities. Besides, the idea aims at developing a sense of identity from the users to the building, which was unexciting due to the original structure image that was the result of a fast and generic architecture.

Such the original building as the proposal were assess into different simulation programs, which allowed to determine the deficiencies of the original building, the strategies to be adopted and to finally verify how the intervention influenced over the original project. The results revealed that with the use of an exoskeleton, there is a possible way to solve the building's structural deficiencies to enhance its structural stiffness to resist any seismic activity. On the other hand, the implemented technological approaches shown to improve not only the buildings comfort quality and image, but also its energetic performance, and by introducing the solar cells, the building's energy demand will be cover by its own energy production, fitting the Near to Zero Emissions Building Standards.

The intervention was also taken into advantage to improve the building's functionality by adding needed spaces and uses, such as vertical circulation cores and multipurpose areas. It also allows the expansion of existing spaces in the building to cover space demand and to improve the current internal qualities of the edifice.

In conclusion, the integrative approach of the exoskeleton with technologies for energetic efficiency is a feasible solution to be applied to different types of exhausted service lifespan buildings, allowing to take advantage of the existent structure, reducing waste production, enlarging the lifespan of the building and renewing its general image. Overall, it is a sustainable approach that can be applied worldwide while still remaining as one-of-a-kind for each project.

10

References

10

References

[1] R. K. Dhir OBE, J. de Brito, R. V. Silva and C. Qun Lye “Sustainable Construction Materials: Recycled Aggregates”, Woodheah Publishing Series in Civil and Structural Engineering, pp. 419-421, January 2019

[2] European Commission 2012, “Energy-efficient buildings PPP beyond 2013-Research and Renovation Roadmap”, Document for E2B European Iniciative (ECTP), 2012

[3] L. Mazzarella, “Energy retrofit of historic and existing buildings. The legislative and regulatory point of view”, Energy Build, pp 23-31, 2015

[4] A. Ballerini, A. Marini, “Does sismic rick affect the environmental impact of existing buildings?”, Energy and Buildings, vol. 110, pp 149-158, 2015

[5] G. Mangliulo, M. Ercolino, C. Petrone, O. Coppola and G. Manfredi, “Why did many precast RC Buildings collapse during the 2012 Emilia earthquakes?” Second European Conference on earthquake engineering

and seismology, Istanbul, pp. 3-8, 2014

[6] E-S. Georgescu, M. Georgescu, Z. Macri, E. M. Marino, G. Margani, V. Meita, R. Pana, S. M. Cascone, H. Petran, P. P. Rossi, V. Sapienza and M. Voica, “Seismic and Energy Renovation: A Review of the Code Requirements and Solutions in Italy and Romania”, Sustainability 2018, pp 1-3

[7] G. scuderi “Building Exoskeletons for the Integrated Retrofit of Social Housing”, Civil Engineering Journal, Vol 2, pp 226-230, 2016

[8] S. D’Urso and B. Cicero, “From the Efficiency of Nature to Parametric Design. A Holistic Approach for Sustainable Building Renovation is Seismic Regions”, Sustainability 2019, vol. 11 , pp 1-3, February 2019

[9] JCR Scientific and Policy Reports, A. Marini, C. Passoni, P. Riva, P. Negro, E. Romano and F. Taucer, “Technology options for earthquake resistant, eco-efficient buildings in Europe: Research Needs”, European Commission, pp 3-15, 2014

[10] S. Labò, C. Passoni, A. Marini, A. Belleri, G. Camata, P. Riva and E. Spacone, “Diagrid solutions for a sustainable seismic, energy and architectural upgrade of European RC buildings”, Cinpar 2016, pp 1-5, 2016

[11] Federal Office for Spatial Development, “1987: Brundtland Report” [Online source]. Available URL: https://www.are.admin.ch/are/en/home/sustainable-development/international-cooperation/2030agenda/un-_-milestones-in-sustainable-development/1987--brundtland-report.html

[12] Intelligent Economist, “Malthusian Theory of Population” [Online source]. Available URL: https://www.intelligenteconomist.com/malthusian-theory/

[13] United Nations, “Report of the World Commission on Environment and Development: Our Common Future”, UN Documents, 1987

[14] Unicef “Sustainable Development starts and ends with safe, healthy and well educated children”, A post-2015 world fit for children, pp 1-6, 2013

[15] United Nations, SD21, “Review of implementation of Agenda 21 and the Rio Principles: Synthesis”, Formatoverde.pt, pp 1-12, 2012

[16] United Nations, “Sustainable Development Goals” [Online source]. Available URL: https://sustainabledevelopment.un.org/?menu=1300

[17] Ente Nazionale Italiano di Unificazione [Online source]. Available URL: http://www.uni.com/index.php?option=com_content&view=article&id=141&Itemid=2422

[18] E. Fregonara, “Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali”, Edizioni Franco Agnelli, First edition, pp 11-24, 2015

[19] ENEA, “Osservatorio Nazionale degli edifici a Energia quasi Zero NZEB-Sempre più numerose le adesioni al progetto ENEA” [Online source]. Available URL: http://www.enea.it/it/efficienza-energetica/osservatorio-nazionale-degli-edifici-a-energia-quasi-zero-nzeb-sempre-piu-numerose-le-adesioni-al-

progetto-enea

[20] ASVIS: Alleanza Italiana per lo Sviluppo Sostenibile "L'Italia e gli Obiettivi di Sviluppo Sostenibile", Rapporto AsviS, pp 5-6 29-31, 2017

[21] ISO "ISO 14040:2006 - Environmental Management – Life Cycle Assessment – Principles and Framework" [Online source]. Available URL: https://www.iso.org/standard/37456.html

[22] ISO "International Standard ISO 15686-5:2008 – Buildings and contracted assets – Service life planning – Part 5: Life-Cycle Costing" [Online source]. Available URL: https://www.iso.org/standard/39843.html

[23] Global Footpirnt Network "Ecological Footprint" [Online source]. Available URL: https://www.footprintnetwork.org/our-work/ecological-footprint/

[24] WWF "Ecological Footprint" [Online source]. Available URL: https://wwf.panda.org/knowledge_hub/teacher_resources/webfieldtrips/ecological_balance/eco_footprint/

[25] Time for a Change "What if a carbon footprint?" [Online source]. Available URL: https://timeforchange.org/what-is-a-carbon-footprint-definition

[26] European Commission "Embodied energy" [Online source]. Available URL: https://ec.europa.eu/energy/en/eu-buildings-factsheets-topics-tree/embodied-energy

[27] Cambridge Dictionary, "Holistic" [Online source]. Available URL: https://dictionary.cambridge.org/dictionary/english/holistic

[28] Enclyclopaedia Britannica "Recycling" [Online source]. Available URL: https://www.britannica.com/science/recycling

[29] R. Montesa "Sobre reutilización, reciclado, reciclaje, upcycling y downcycling" [Online source]. Available URL: https://rosamontesa.wordpress.com/2014/05/02/sobre-reutilizacion-reciclado-reciclaje-upcycling-y-downcycling/

[30] Terri Meyer Boake, "Diagrid Structures: Systems, Connections, Details", Birkhauser/Basel, pp 13-17 61-70, 2014

[31] R. S. Joshi, D. J. Dhyani, "A Review on Novel Structual Development in Tall Building: Diagrid Structure", Scientific journal of impact Factor, vol 4.72, pp 70-71, 2017

[32] A. Marini, C. Passoni, A. Belleri, F. Feroldi, M. Preti, G. Metelli, P. Riva, E. Giuriani and G. Plizzari, "Combining seismic retrofit with energy refurbishment for the sustainable renovation of RC buildings" European Journal of Environmental and Civil Engineering, pp 1-9, 2017

[33] S. Labò, C. Passoni, A. Marini, G. Camata, A. Belleri, P. Riva, E. Spacone, "Prefabricated Responsive Diagrids for Holistic Renovation of Existing Mid-Rise RC Buildings", ECCOMAS Proceedia, pp 4235-4237, 2017

[34] F. Feroldi, A. Marini, A. Belleri, C. Passoni, P. Riva, M. Preti, E. Giuriani and G. Plizzari, “Miglioramento e adeguamento sismico di edifici contemporanei mediante approcio integrato energetico, architettonico e strutturale con soluzioni a doppio involucro a minimo impatto ambientale”, Progettazione Sismica, vol. 5, N. 2, pp 32-36, 2014

[35] M. Barozzi, J. Lienhard, A. Zanelli and C. Monticelli, “The sustainability of adaptive envelopes: developments of kinetic architecture”, Procedia Engineering, vol 155, pp 275-277, 2016

[36] E-S. Georgescu, M. Georgescu, Z. Macri, E. M. Marino, G. Margani, V. Meita, R. Pana, S. M. Cascone, H. Petran, P. P. Rossi, V. Sapienza and M. Voica, “Seismic and Energy Renovation: A Review of the Code Requirements and Solutions in Italy and Romania”, Sustainability 2018, pp 14-18

[37] STS Software Tecnico Scientifico, “CDW WIN Struttre C.A., Acciaio e Legno” [Online source]. Available URL: http://www.stsweb.it/prodotti/strutturali/cdswin.html

[38] Design Builder, “Welcome to DesignBuilder V5” [Online Source]. Available URL: https://designbuilder.co.uk/helpv5.5/#GetStarted.htm%3FTocPath%3DGet%2520Started%7C_____0

[39] Istituto Comprensivo Bordighera “Secondaria di 1mo grado Giovanni Ruffini” [Online source]. Available URL: https://www.istitutocomprensivobordighera.edu.it/scuola-secondaria-di-i-grado-giuseppe-ruffini/

[40] Scuola in Chiaro, “Bordighera “G. Ruffini”” [Online source]. Available URL: http://cercalatuascuola.istruzione.it/cercalatuascuola/istituti/IMMM80801R/bordighera-gruffini/

[41] World Weather Online, “Bordighera Monthly Climate Averages” [Online source]. Available URL: https://www.worldweatheronline.com/bordighera-weather-averages/liguria/it.aspx

[42] World Weather and Climate Information, “Climate and average monthly weather in Bordighera (Liguria), Italy” [Online source]. Available URL: https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,bordighera-liguria-it,Italy

[43] Meteoblue, “Wind Rose Bordighera, Liguria, Italy” [Online source]. Available URL: https://www.meteoblue.com/en/products/historyplus/windrose/bordighera_italy_3181864

[44] T. Sammut-Bonnici and D. Galea, “SWOT Analysis”, ResearchGate, pp 1-8, 2015

[45] Solaronix, “Solaronix Solar Cells” [Online source]. Available URL: https://www.solaronix.com/solarcells/