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TESI DI LAUREA

APPLYING BIOMIMETIC APPROACH FOR ENERGETICAL RETROFIT OF THE RAI SKYSCRAPER IN TURIN

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LAST BUT NOT LEAST, FAMILY. FAMILY OF HOME UNIVERSITY AND THE WORLD.

"When we look at what is truly sustainable, the only real model that has worked over long periods of time is the natural world."

Janine Benyus

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0. Introduction

The aimed building to be studied is the Rai skyscraper which rises in the boundaries of the historical city center, between the Cernaia avenue, Guicciardini street, Fratelli Ruffini street and piazza XVIII Dicembre. It has a height of 72 m making it one of the tallest buildings in the city. It is the first skyscraper of Turin. The building belongs to RAI (Radio Televisione Italiana, the national broadcasting service) and has been abandoned since 2014 due to high energetical costs and safety issues.

Figure 1 View of the context around the site
SOURCE: Open Street Map

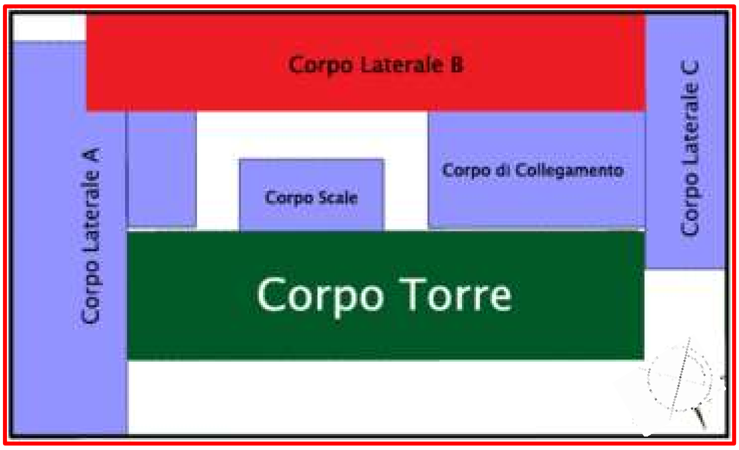


Figure 2 The different facilities of the complex RAI
SOURCE: author

The complex is composed by a central skyscraper (copo torre) together with the stairs structure (corpo scale) and three smaller bodies (corpi bassi A B C). The principal façades are exposed in and North West (the external one facing XVIII Dicembre square) and South East (the internal one). The plant has a rectangular shape with a total area of around 690 m^2. The ratio of glazed surface is around 85%

0.1 Abstract

The goal of this analysis is to propose new functions for this building, considering its full potential to be transformed in a multifunctional office for the RAI group employees. The edifice is first analyzed from a broader perspective, considering its impact on the surrounding context and then its characteristics will be studied. The transformations that have occurred in time are represented as an integrate part of the study through a chronology of all-important events, since the first concept until the date in which it stopped functioning. Before proposing new functions for the building an overall study is made. It concerns the site, the edifice, its design process, the spaces, the structure, the materials the services and the architect who followed the entire construction. The specific focus of design regards the skyscraper envelope to reach a notable cost reduction. The design intervention takes into consideration a **biomimetic** approach. The living architecture embraces the traditional and modern elements of this facility to transform it in a contemporary model office building.

1. Site analysis

This preliminary phase is very significant for the finalities of the design, since its dedicated to the study of the climatic, geographical, historical, legal, and infrastructural context of a specific site. Initially is shown the general architecture in the city from ancient to modern times. Then a study of the area where the building is constructed is carried on showing the major transformations since the initial plans and successive developments. A specific part regards the booming Italian years when the construction took place. This chapter is concluded with the actual regulatory plan that will serve as a legal and guiding instrument for the future interventions in the facility.

1.1. Architecture in Turin

Turin is an ancient city, where a mix of architectures cohabit in harmony with each other. The baroque masterpieces and liberty are intricated with the most modern structures designed by the architects of our days for the Olympic games in 2006. [1]

The Palatine Gate represents the primary archaeological evidence of the city's Roman phase and is one of the best preserved 1st-century BC Roman gateways in the world. Together with the ancient theatre's remains, located a short distance away, it is part of the so-called Archaeological Park, opened in the same year of the Olympics. The successive era, that of baroque architecture produces some of the most important objects designed by architects like Guarino Guarini, Filippo Juvarra and Benedetto Alfieri. Furthermore, the form of the principal streets is designed in that epoch. During the nineteenth century and the twentieth, the biggest square of Europe in arcades is built next to river Po, the Vittorio Veneto square. The following century was characterized by a rationalistic architecture, where the biggest automobile manufacturing factory, that of FIAT was built in Lingotto together with some other important structures built by famous Italian civil engineers like Pier Luigi Nervi, which celebrated the centenary of the Italian independence in 1961.

The concrete evolution that was experimented in pre and post war years explodes in the'70 and it sets the base of the future avantgarde transformations. These were the booming years which placed many new buildings with the latest technology, that of reinforced, prestressed and pretensed concrete. The building object of study belongs to the contemporary architecture in Turin and was built in the end of the year 1968. The city later became appetible for some "archistars" like M. Fuksas, A. Isozaki, R. Piano and many others who also designed some buildings for the 2006 Olympic games.

[1] Torino Plus. *Architettura.* Web. 7 September 2018. http://www.comune.torino.it/torinoplus/Portrait_nuovo/architettura/index.shtml

The map below is a representation of the cohabiting architectures in Turin in a scale of 1:20.000 approx. It is retrieved from the study of the regulatory plan of the City of Turin dating back in 1994. It can be noticed easily the diversity of the styles and their unique mixture. The legend denotes the centuries when the buildings are established.

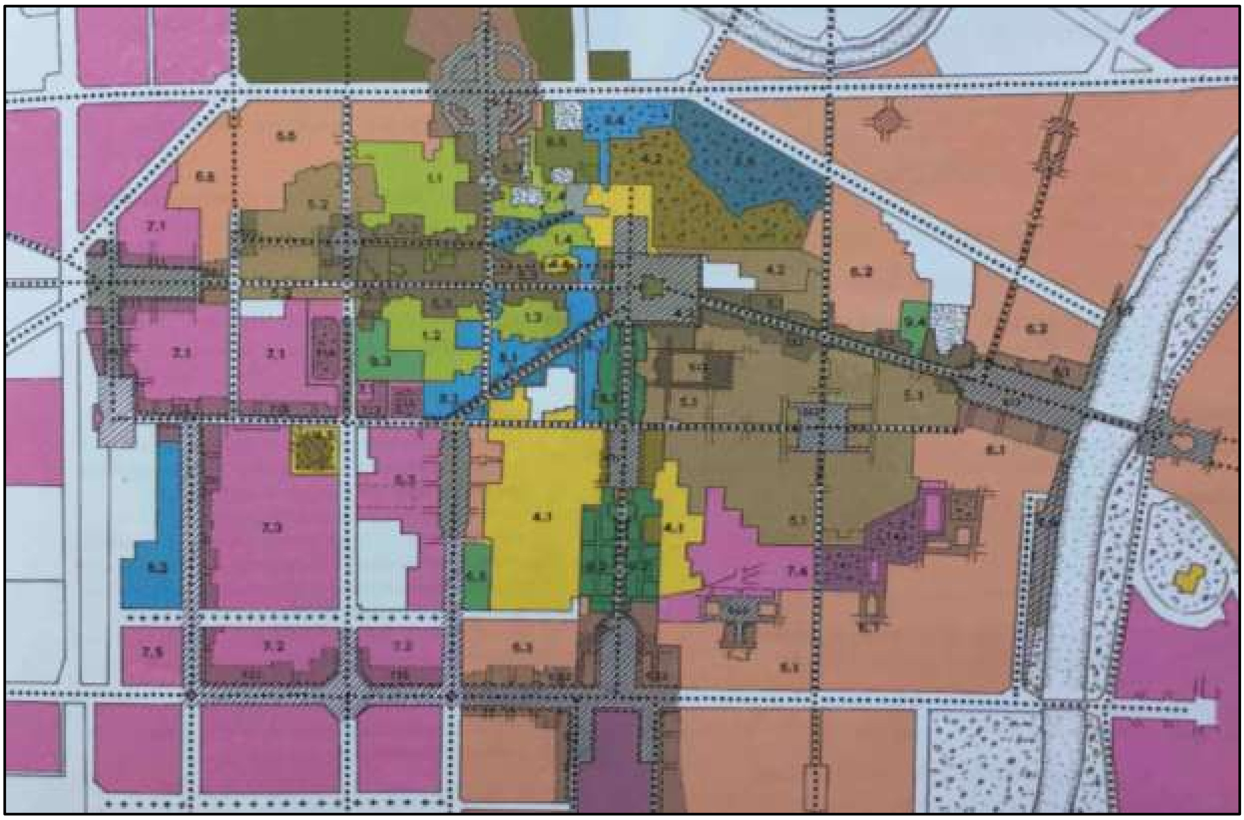
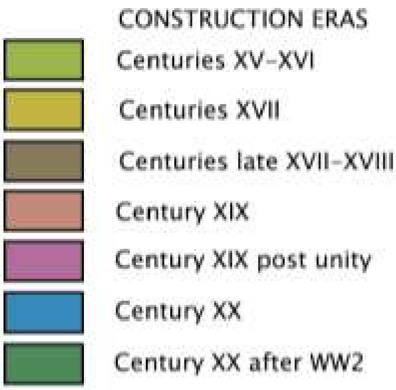


Figure 3 Historic urban areas in the central area of Turin
SOURCE: (Dipartimento di Ingegneria dei Sistemi Edilizi e Territoriali del Politecnico di Torino, 1994)



1.2. The major transformations in the interested area.

Why studying the history one hundred years before the actual construction?

Perhaps by passing on the history of the fief[2] *with a book, future generations will be able to know the past and understand its essence.* [1]

It is important to understand the history of the surrounding area to make future proposals. Before making the study of the period when the building was constructed, a quick timeline of the major transformations that occurred in the area are represented. The study is made starting from the ideas of the expansion beyond the old city fortifications considering the drivers like the implementation of the latest technology of the railroads. The station itself dates in 1856 in an ecclesial-classical style. The actual building is constructed in the economic boom years and was completed in 1968. To reach these two milestones, a representation of different urban plans will be made. It will be divided in two parts, the plans and the realization. First, a comment of the plans and their main conclusions are drawn. Then the study represents the realization of constructions and all the difficulties and deviations that occurred until the completions. The data was obtained from the book "Ambienti e tessuti urbani storici nella zona centrale di Torino" [2]

1.2.1. The Plans

In the years between 1846 and 1857, plans were drawn up for urban expansion in the area in question This development took place in several times in relation to changing needs and boundary situations.

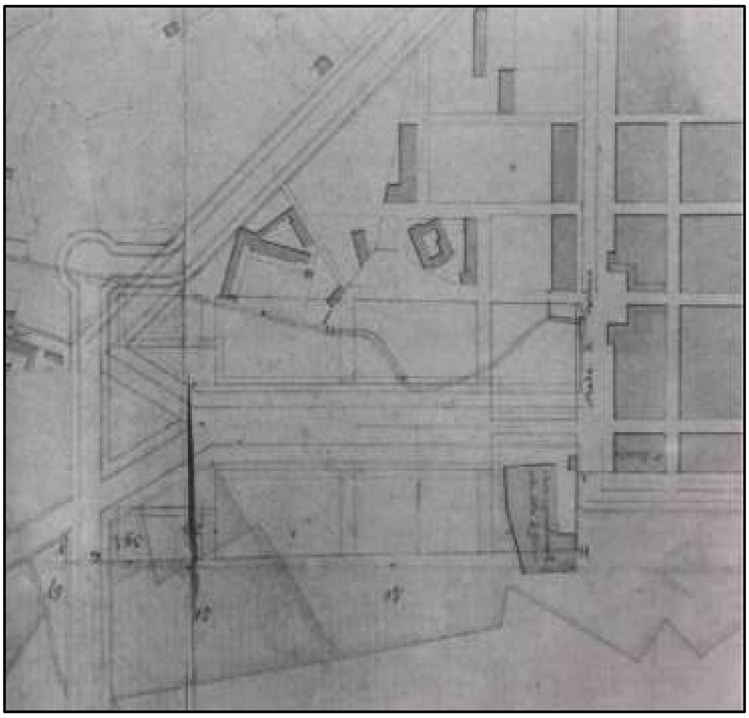


Figure 4 The plan MOSCA, BARONE, BRUNATI of 1846 for the piazza "outside Porta Susa"
SOURCE: DISET

The Plan MOSCA BARONE BRUNATI, 1846

The plan constituted a planimetric design of the future Piazza Statuto already substantially close to what would be built and completed thirty years later. In the same year, the project with the new constructions that would have taken place in Porta Susa was reported in the geometric plan defining the polygon of military easements, attached to the Royal Licenses of 6 June 1846 and 26 January 1847. The major proposals regarded the usage of arcades and the widening of the streets in the area.

[2] A different expression for city

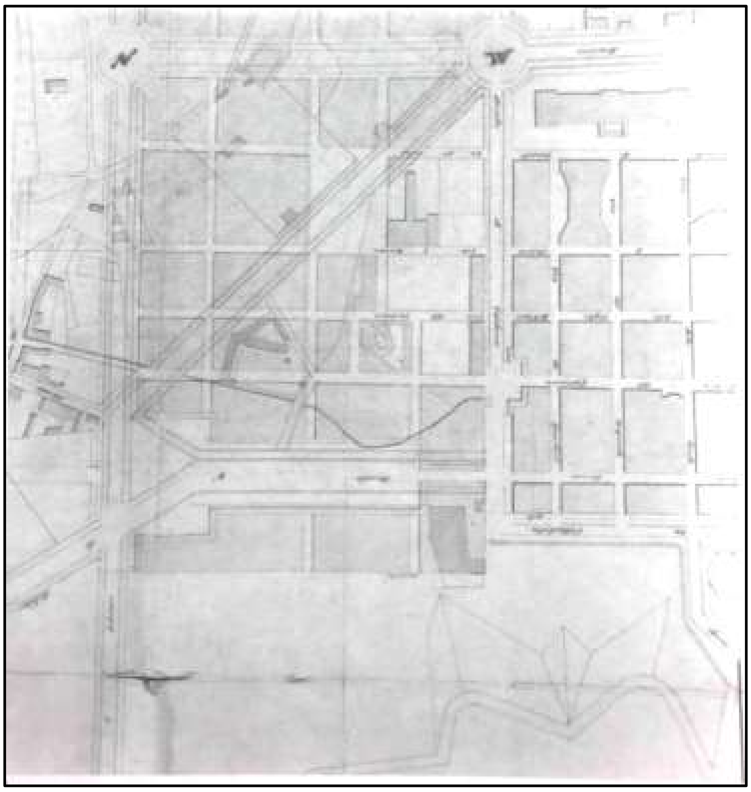


Figure 5 The PROMIS plan, dated 1851, for outsidei Porta Susa and in the Valdocco region SOURCE: DISET

The PROMIS Plan, 1851

The second important moment for the area was the approval of the Promis plan, designed by the professor Promis. It took into consideration the previous plan for the Piazza Statuto and proposed the elimination of the buildings with trapezoidal forms. It stated that the buildings should have a maximum height of 21 meters with at most 5 floors, including the ground floor and the mezzanine-floor; it was taken into consideration the possibility of building dormers to make the attics habitable.

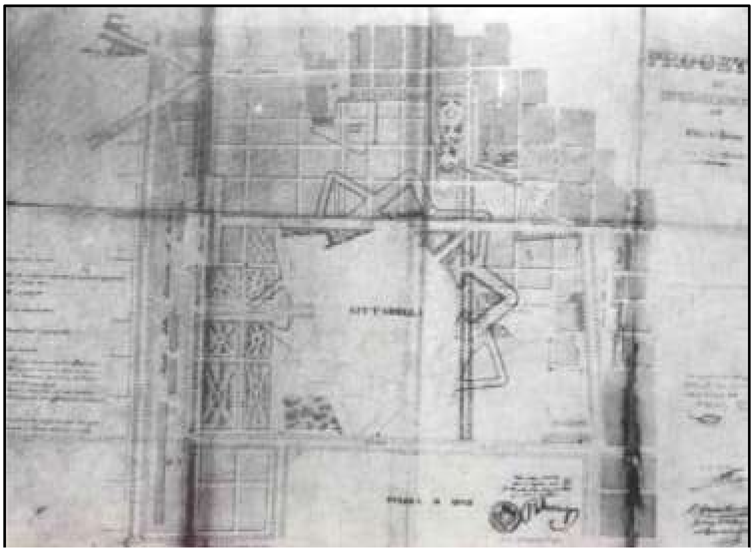


Figure 6 The PECCO plan for the enlargement towards the ex-Cittadella (central section) of 1857 SOURCE: DISET

The PECCO Plan, 1857-1858

In a third moment, in the six years between 1851 and 1857, the plan for the enlargement towards the Citadel was developed, closely connected to the difficult urban problem of the location of the railway station of Novara and its connection with the city center.

In the end, the enlargement plan towards the Cittadella basically confirmed the original idea of Promis:

the junction of piazza Statuto would be separated and offset from the node of the railway station located at the end of the (current via **Cernaia**) of the ancient city artery of Via Santa Teresa (directed to Piazza S. Carlo and Piazza Carlina). The plan definitively fixed the position of the Novara Railroad and established the opening of the avenue connected to Piazza Statuto

The buildings were reduced in size compared to the plan of 1846. Furthermore, the porticoed facades, on Via **Cernaia**, Piazza XVIII Dicembre and Corso San Martino, were to conform to the rules and designs established for the porticoes of Piazza Statuto approved by Royal Decree of 11 August 1851: the height of the cornice had to remain the same all the blocks and the arcades had to be continued with terraces. This plan was approved by the government and many incentives were given to the builders who respected the requisites. The figure below shows a house in Cernaia avenue and its successive transformation.

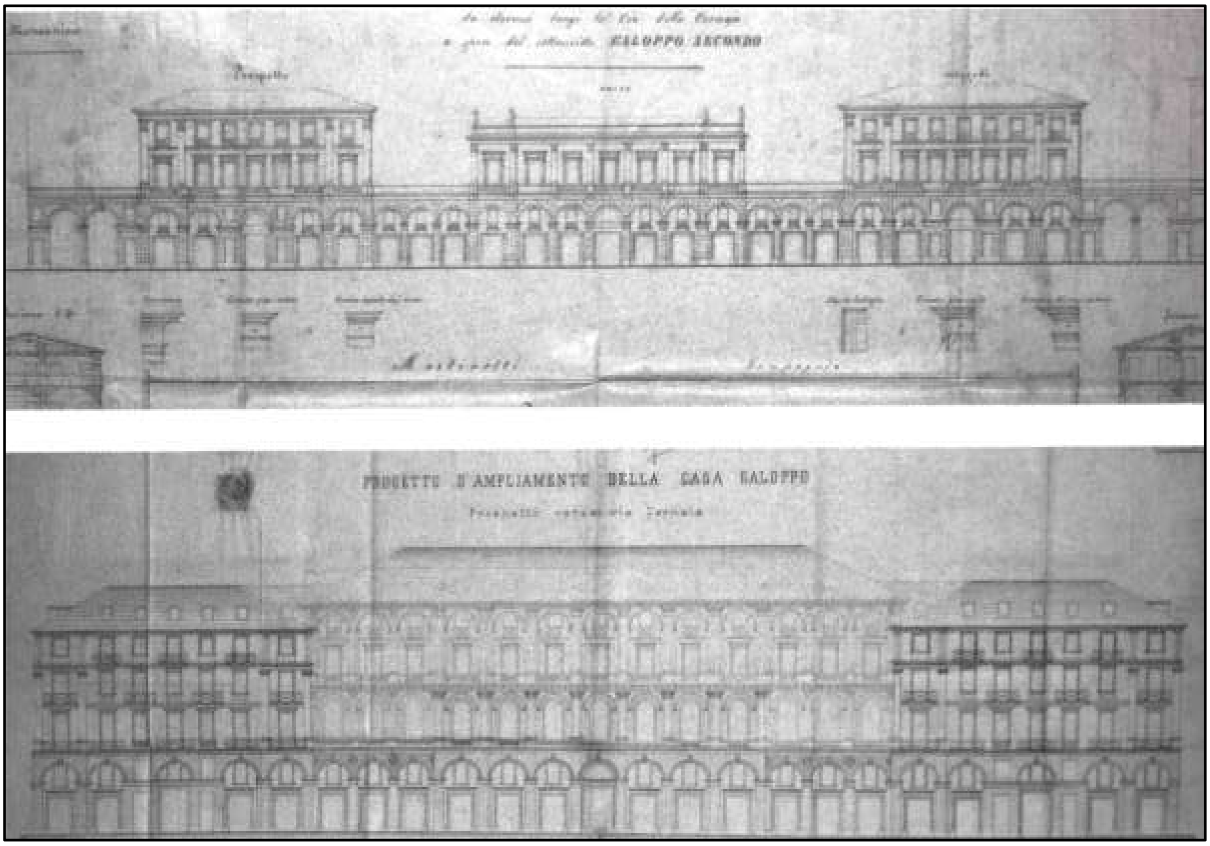


Figure 7 (above) The housing complex Galoppo Palace located in avenue Cernaia
(below) the successive extension 1879
SOURCE: DISET

1.2.2. The implementation

The first realization phase from mid-1800's till 1864

The map of the Cadaster RABBINI configures the building situation roughly in the years of the Second War of Independence and of the Unity of Italy. The map shows the network of streets and squares designed for the expansion towards Porta Susa; but in this network there are still very few buildings completed: the porticoed Molines house (headquartered in Piazza Statuto, north of Via Garibaldi) and some other buildings.

Figure 8 The RABBINI cadastre
SOURCE: DISET

The projects for buildings the arcades in Via Cernaia and in Piazza Statuto

The historical phase was characterized by buildings and large-scale construction projects on the main urban spaces' porticoes provided by the plans:

Avenue **Cernaia** (alleging the railway station of Porta Susa) was conceived on fronts uniformed by special rules on heights and eurythmy and symmetry of the blocks.

The buildings on Via **Cernaia** were conceived according to a less rigid model: they assumed unitary aggregate configurations isolated by block, with large spaces inside, connecting the courtyards of the various properties at the top.From a more strictly architectural point of view, these buildings, designed for Piazza Statuto and Via **Cernaia** in the short period between 1861 and 1864, fully responded to the intentions of the plans, governed by the regulations already illustrated.

This period was followed with a building crisis that came because of the capital transferring in Florence.

The successive interventions of late-1800's and first years of 1900

The comparison of the Supplemental Map of the Municipal Cadaster of 1875, with the map of the Land Registry of year 1905, allows to locate the building events of the last quarter of the nineteenth century and the first glimpse of the twentieth century. These events mainly consist of the following intervention categories:

a) Building redevelopment and intensification
b) Superstructures and additions of bodies
c) Building of new blocks

The successive periods included the years of war and are not treated since they did not bring changes in the conception of the city. Next paragraph will focus on the economic booming years that building was constructed.

1.3 Economical Booming in Italy

The rebuilding of Italian cities, those damaged from the bombing was challenging due to many reasons. First of them was the need for shelter, followed by a scarcity in materials and an overgrowing immigration from the southern provinces.

In a technical point of view the first constructions respected the tradition, after that, some general plans adopted the industrialization techniques whose quality proved not to be the best. Later in the booming years, different neighborhoods were built to supply the demand of a continuous increase of population. These buildings experimented different techniques, but considering the high demands for homes, lack of study time and rapid construction, the results proved not to be the best. Some exceptions occurred, but considering the bigger picture, it proved to be a failure in integrating these parts with the existing city and creating social healthy communities.

1.3.1. The first plans

The need for urban regeneration and rebuilt was immediate in the post war Turin, since almost 1/3 of the building heritage was destroyed by bombing. The first plan which won the competition was the ABBR proposal for designing a series of organic unities that would be economically active. This plan was too extrovert for the Turin officials who decided not to follow it, but to charge Giorgio Rigotti and Sandro Molli Boffa, with the duty of elaborating a new plan. The new plan considered the expansion of the city imitating the star shape. This plan accepted the cohabiting of industrial areas with the residential ones and imposed some environmental rules (use of 7m^2 of green space per inhabitant). In the meantime, the plan was approved 5000 building permits were issued which compromised its effectiveness of the rules in the rapidly rebuilding city. [3]

1.3.2. The economic boom

The Marshall plan for the rebuilding of Europe was a great help for the city of Turin, since Fiat was one of the biggest companies that took advantage of it. The low cost of labor and the expansion of automotive industry brought many possibilities in the new city. This was perhaps the biggest reason of immigration from south of Italy of a great mass of people that within twenty years contributed to the surpassing of 1 million of inhabitants in Turin. The need for shelter was the first demand so after the economic boom, the following was the construction boom. The increase of construction workers was more than 1.3% whose total 80% were immigrants from south. Before the facilities were created, people used to live in provisional solutions called "casermette" in poor houses in the center and other suburban areas. This increase in population was so rapid as sources say from 1951 to 1961 the increase was 10% counting around 310.000 people. In these years an important law called PEEP was approved which included some important building guidelines.

The new neighborhoods

The construction boom was concentrated in the suburbs of the city where half of the population used to live according to the registry of the year 1971. "The new construction facilities were planned in the margins of the historical city, from north to south, in the plain ground along the antique web of the farmhouses that constituted from centuries until the second world war the skeleton of agriculture of the region which were consequently demolished by the new edifices".[3] Pg69 [3].

The neighborhood building represented a very significant moment for the public interventions. It

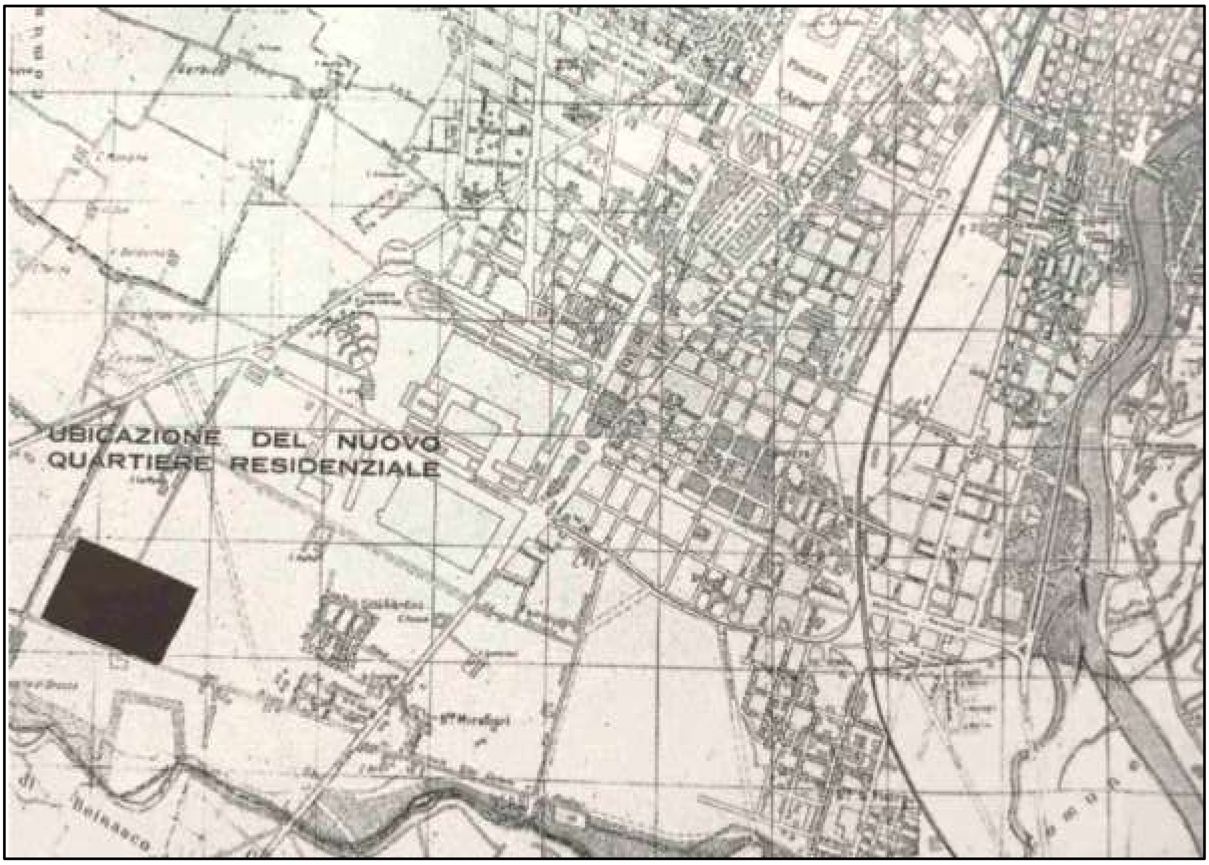


Figure 9 Location of the building site of Mirafiori Sud, one of the planned neighborhoods. SOURCE: Garda Mangosio Mele Ostorero, 2015)

was the first one to implement in a large scale the prefabrication techniques. The name comes from the Fiat establishment and the total area is 550.000 m^2. The final product consisted on 15 fabricated objects containing 768 residential units. They were disposed in three types characterized by different lengths as can be seen from the figure above. Even though the techniques were the latest the problems appeared soon, and the main causes were the location (distant from the city center), the big social differences between the residential units and the lack of common facilities. In nowadays optics, perhaps the biggest problem lies in the retrofitting of these houses to comply with the latest energetical requirements. Next page starts with an aerial view of the area which nowadays need to be re concepted as stated by the book authors.

[3] C. Mele, *Valigie di cartone e case di cemento,* Torino, Celid, 2015, p.69.

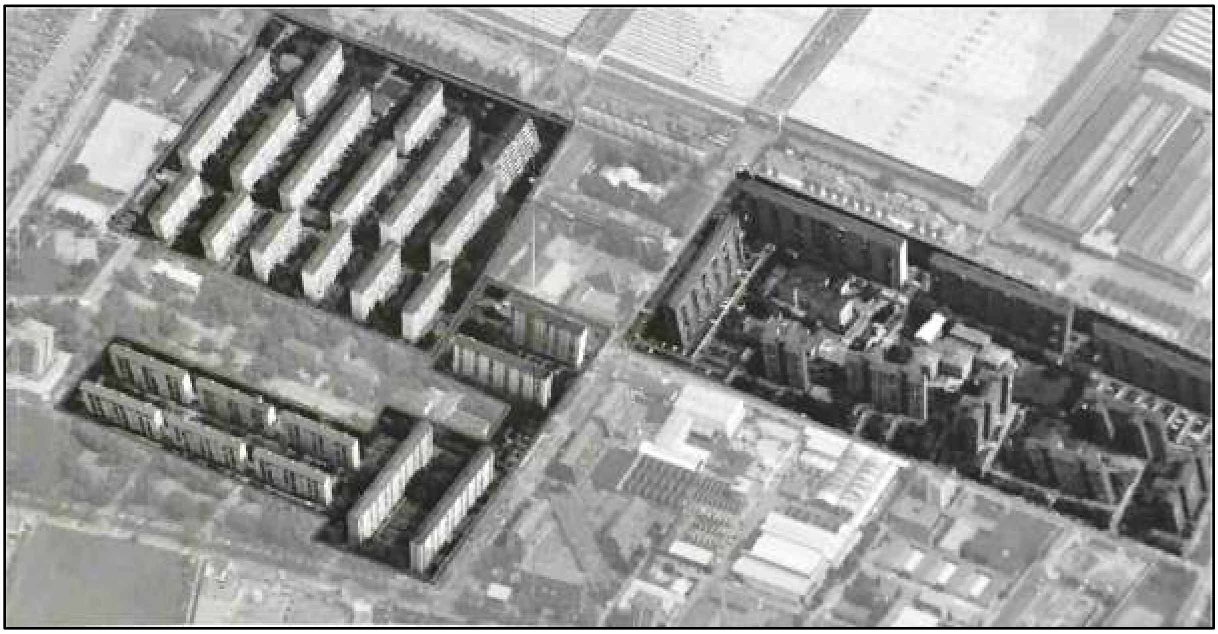


Figure 10 An aerial view of Mirafiori Sud, which was built by prefabricated systems by Borini company. SOURCE: Garda Mangosio Mele Ostorero, 2015)

These requirements are far more restrictive compared to the building time, since they offer the right living comfort. "The requalification of the existing heritage together with other challenges like the social interactions and reuse of industrial land, redesign of suburbs is a theme for redesigning the future of Turin city and other Italian cities in general"[4]. [3]

The new RAI building that was built in contrast to the majority of the constructions

The description of the suburbs is made with the purpose of contrasting the way of designing the new RAI skyscraper. In the meantime, far from the suburbs, in the boundaries of the historical city center, plans were being made for the construction of the Rai facility. To support the statement above, a timeline of all the events is given in the chapter edifice. The client ideas emerged in the years 1950, but the first concept sketches date back on 1959 and the construction phase started only on the year 1961. Keeping in mind what is stated in the previous chapters to have an idea of the level of advancement of industry and the building techniques in general, a more detailed analysis of the building is carried on that is focused on the facility itself.

[4] The conclusion that emerges from this study,C.Mele, *Valigie di cartone e case di cemento,* Torino, Celid, 2015, p.81.

1.4. The present regulatory plan

Before making any proposals for interventions, it is important to study the Urban Plan which is in force for the area that interests the project. So, a research was carried one and the data was obtained from the Turin Municipality official web page that states the following:

1.4.1. What does the legislation dictate?

The Land Use Planning foresees for the RAI skyscraper in via Cernaia a tertiary destination (areas or building complexes of tertiary destination), this is a Regulatory Area inside the Historic Central Urban Area. The use is governed in art. 10 point 6 of Implementation of Urban Planning Standards, the urban and building transformation parameters are those of the belonging area. The building currently results as a private property. [1]

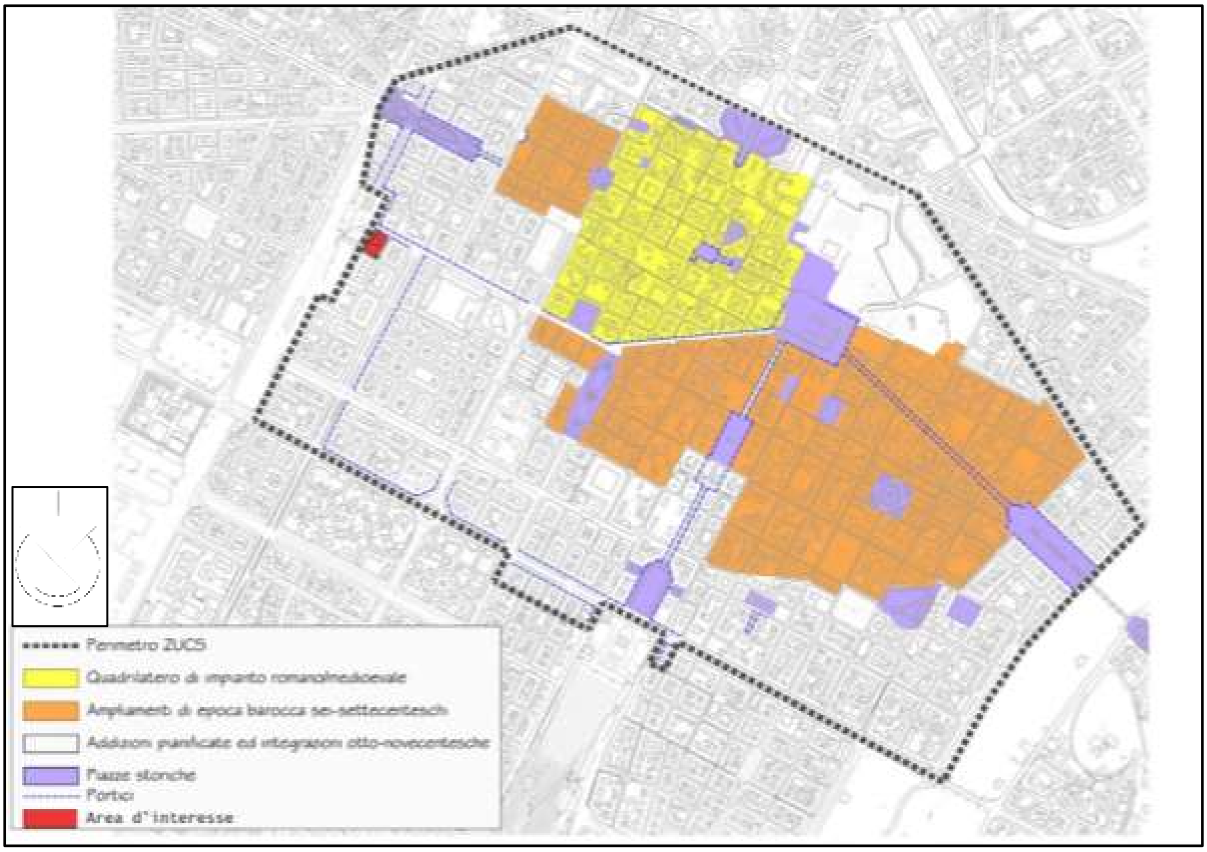


Figure 11 The delimiting area of the historical urban center, evidencing the interested area in red.
SOURCE : Turin Municipality official webpage

Art. 10 - Historic central urban area (Zona urbana centrale storica)

The Plan defines the "historic central urban area" the part of the city identified in the maps in scale 1: 1000 and 1: 5000, bounded by the courses:

Regina Margherita, San Maurizio, Lungo Po Cadorna, Lungo Po Diaz, Cairoli, Vittorio Emanuele, via Saluzzo, via San Pio Porta Nuova, via Magenta, Re Umberto, Vittorio Emanuele II, Bolzano, piazza XVIII Dicembre, via Santarosa, piazza Statuto e Principe Eugenio.

Tabella dei tipi di intervento – Art. 10

Parti degli edifici	Esterno degli edifici su spazi pubblici			Sistema distributivo				Cortili, giardini privati e fronti verso tali spazi			Interno dei corpi di fabbrica	
Qualità delle parti degli edifici	a	b	c	a	b	c	d	a	b	c	a	b
Gruppi di edifici												
1. Edifici di gran prestigio	RES	RES	/	RES	RIS	RES	RIS	RES	RES	RIS	RES	/
2. Edifici di rilevante interesse (tessuti ad alta densità) (tessuti "minori" residui)	RES	RIS	RIE	RES	RIS	RES	RIS	RES	RIS	RIE	RES	RIE
3. Edifici della costruzione ottocentesca della città (tessuti "minori" residui)	RES	RIS	RIE	RIS	RIE	RIS	RIE	RIS	RIS	RIE	RIS	RIE
4. Edifici del complesso di via Roma	RIS	/	/	RIS	RIE	RIS	RIE	RIS	RIS	RIE	RIS	RIE
5. Edifici del periodo tra le due guerre	/	RIS	RIE	RIS	RIE	RIS	RIE	RIS	RIS	RIE	RIS	RIE
6. Edifici recenti	RIS	RIS	RIE	RIE	RIE	RIE	RIE	RIE	RIE	RIE	RIS	RIE

Note: - RES: Restauro conservativo
- RIS: Risanamento conservativo
- RIE: Ristrutturazione edilizia
secondo le definizioni contenute nell'allegato A punti 3 - 4 - 5

Figure 12 The rules defined for specific interventions in the historical area.
SOURCE: Turin Municipality

Within this area, interventions are aimed at protecting architecture and the environment through a correct reading of historical values, urban transformations and events that, over time, have shaped the city. The new opening, the transfer, the variation of the sales area and/or of the merchandise sector of shops in a fixed location that involve building interventions on the buildings located in the historical central urban area, are subject to the verification of the correct integration in the typological context of the buildings adjacent, with particular attention to the inclusion of the showcase spaces, accesses and commercial furnishings taking into account the specific regulations and Annex C with particular reference to Article 14. [5]

1.4.2. The future transformations, Torino 2030.

An urban plan shows what a place could be like in the future according to how we are used to see it. Plans aren't just about what a place may look like in the future as it was concepted before, just a complementary instrument, it has evolved now to a more complex tool. As Treccani defines:
"Town planning has therefore abandoned its concrete expression, the technical fact of the creation of the "form" of the city (which was born as an integrative, complementary study) to seek more specifically its activities, as social research and economic planning -policy[6]."[2].This description serves as a guideline to make a holistic design for the requalification of the construction. The interconnections and futuristic predictions are taken into consideration for a resilient and adaptable project capable to satisfy the committee contemporary requisites as well as respecting the ones of the future generations. The municipality of Turin is organizing a series of encounters in order to involve people's ideas for the future of their city. It is called Torino 2030[7] and its keywords are sustainability and resilience, the codes of a city in a continuous change for better.

[5] For more information the website of Commune provides the answers. http://geoportale.comune.torino.it/web/sites/default/files/mediafiles/nuea_volume_i_0.pdf p.87.
[6] Treccani Encyclopedia. *piano regolatóre*. http://www.treccani.it/enciclopedia/piano-regolatore/ .
[7] The municipality plan for the future: http://www.comune.torino.it/ucstampa/comunicati/article_644.shtml

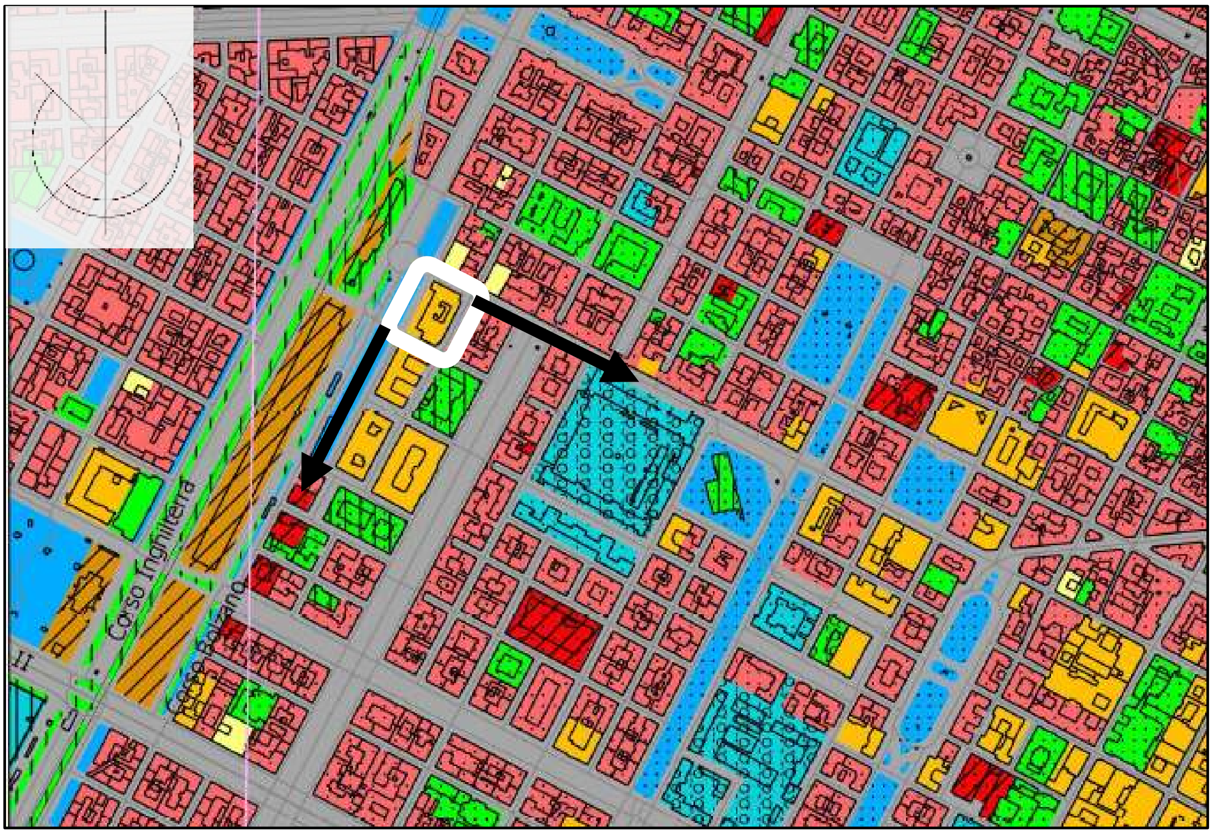


Figura 1 The current urban fabric in the nearby area of the intervention.
SOURCE: TURIN MUNICIPALITY WEBSITE [4]

This map of PRG mosaic, thematizes through a unified legend, the Operator`s destinations with relative territorial conciliation and public facilities and public use, both municipal and supra. The reference scale is 1: 10,000 and the cuts refer to the sections of the RTM (Regional Technical Map). The legend that follows, describes in detail the area close to the site. The two arrows represent two important orientation directions, in the north east is the city center, whereas in the southwest is the Polytechnic of Turin. The legend which explains the map in detail is attached as A1_1.4.2.

2. The edifice

This chapter will analyze the complex in detail, starting from its conception until the final phase. The first section that regards the history, considers the skyscraper together with the lower bodies. Starting from the section 2.2 the focus shifts on the tower only. In the end an evaluation of the current state of the building is made, supported by a site inspection and the information given by the BM and the facility employees. This chapter is probably the most important one since the dynamics of design is different compared to the typical one, considering that the building is a heritage gem of the city.

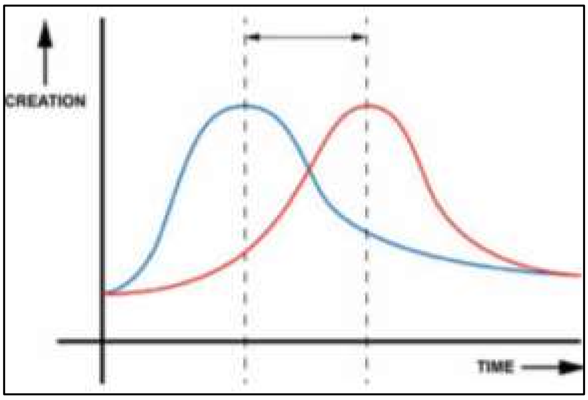


Figure 13 The design dynamics of this case study is represented in red.
SOURCE: Design from Heritage.

As Wessel de Jonge explains from his book "Design from heritage" :

"This is an example of so-called 'research-based design'; a methodology with specifc characteristics. The creative curve in research-based design shows how the creative process builds on a basis of researchand interpretation that precede the actual design process"[8]. Keeping in mind this description of de Jonge who has applied it to some significant refurbishmets (Van Nelle factory in Rotterdam) it was then proceeded with the analysis of the building.

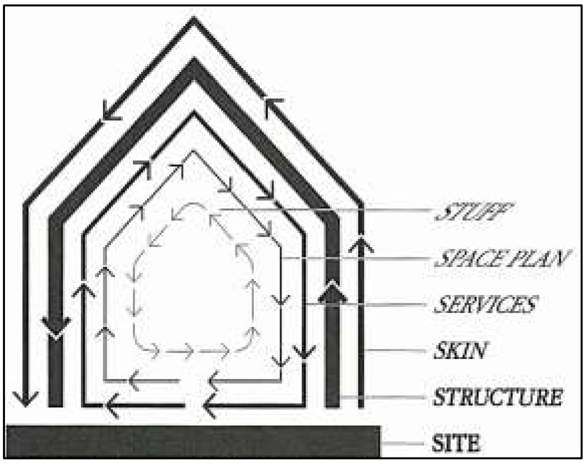


Figure 14 The six layers principle.
Source: Steward Brand "How buildings learn"

To make the anamnesis of the building starting from the section 2.2. the six layers principle was partially adopted for this case study, due to its efficacity on simplifying the complicated picture of the building as a whole. This method makes aware the user of the integral parts of a building and their different rate of change. The six layers starting from top to bottom have a changing time which is inversely proportional. The stuff rate of change is more frequent than that of the site if we consider the two extremes. It is thought as a useful tool to determine the interrelations between the elements and oversee their state of degradation. The design follows this analysis that was first promoted by Stewart Brand in 1992 in his book "How buildings learn".

[8] M. Kuipers W. de Jonge "*Designing from Heritage –Strategies for Conservation and Conversion*"

2.1. History

In the moment when the project was announced, part of the arcades of the in the historical city center were incomplete. Nearby the site there was unavailability to build from the side occupied by the antique customs (which were transformed in two ministerial edifices after war) and the construction of the embankment that gives access to the overpass of the railway station. In the map, the embankment and two buildings nearby the site are evidenced in red arrow and two boundaries. The many different proposals to interfere in that context were unsuccessful since it was situated in the frontier of the historical center. This were the conditions in which the design idea would have been asked to the architects.

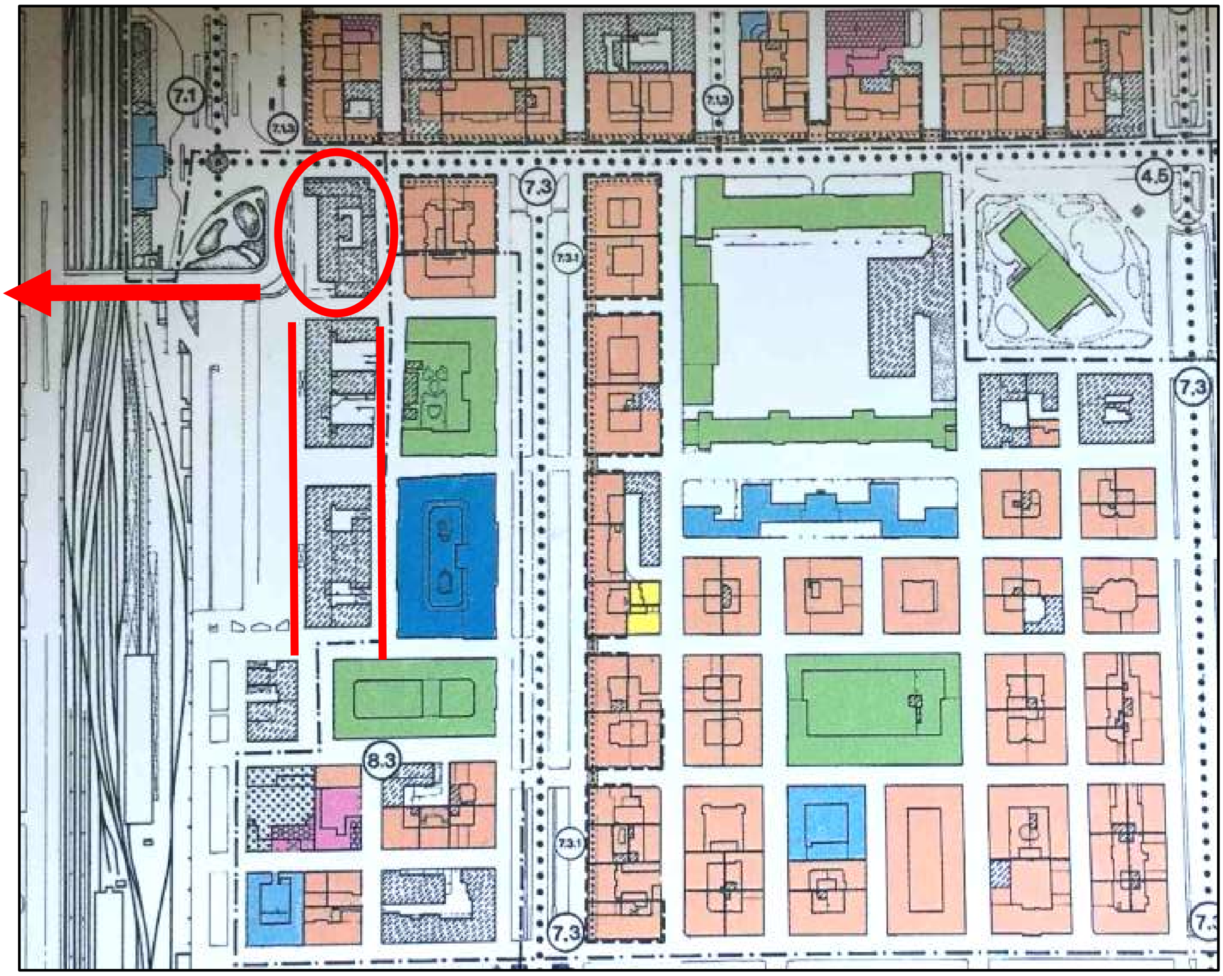
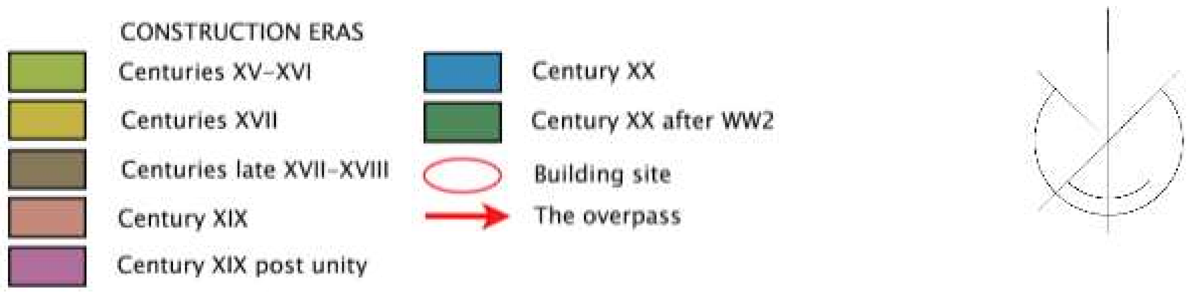


Figure 15 The context before building conception.
SOURCE: DISEG



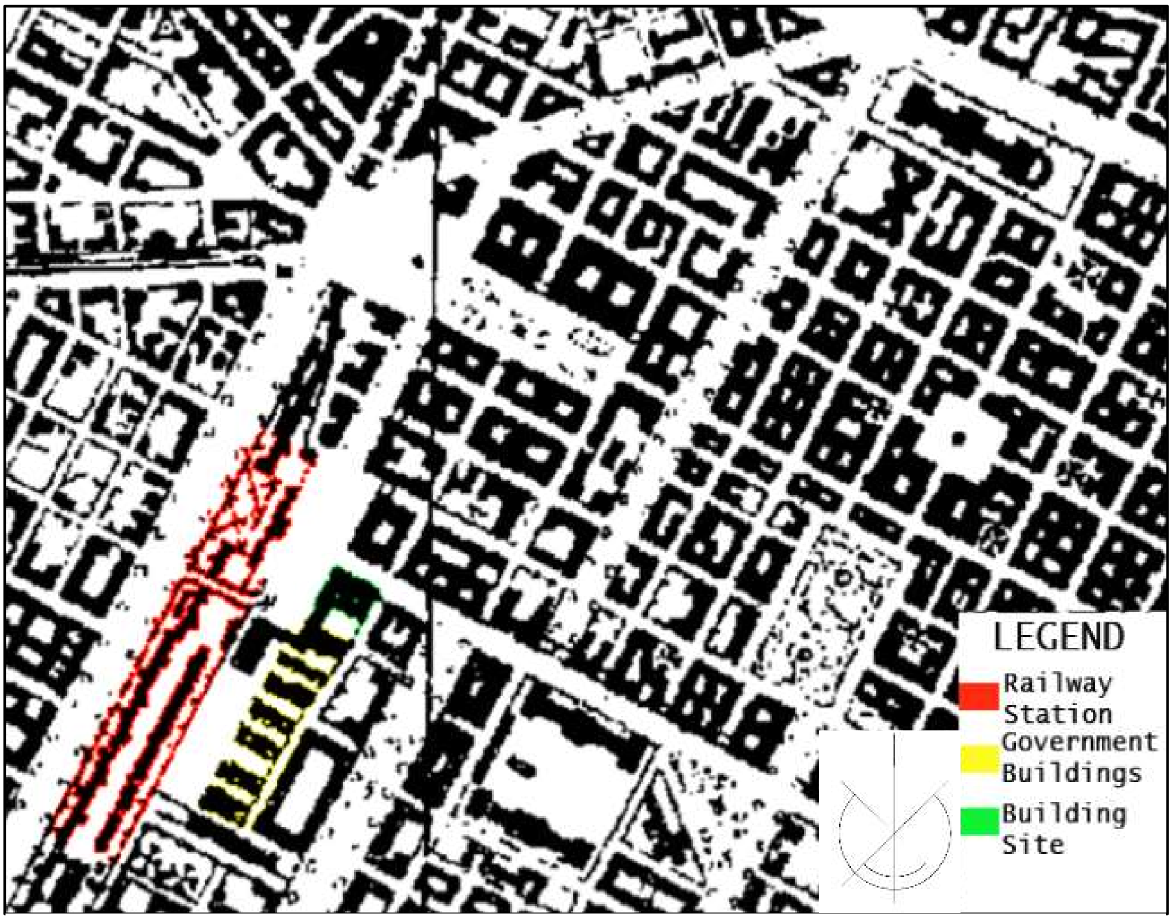


Figure 16 The situation of the immediate area
SOURCE: IGM 1964 scale 1:10000 app

The architects had to operate in this complex situation. They had to deal contemporary with many problems and constraints like the accused rupture of 1800's perspectives, an important aspect of the Turin city. This pretend had to be resolved carefully by respecting the existent context of high value. The requests from the customer changed and became more demanding, intreating more volume than it was initially predicted. This induced an additional problem of traffic congestion, which was already an issue in the zone since the station of Porta Susa is in front of it. The building is born in a moment of economic boom (as previously stated in the 1.3.2. section) where the tertiary sector was expanding rapidly. The unstudied and rapid design was the motto for majority of the designers and builders of that time. The exception was the skyscraper RAI team. "They designed a building complex in complete harmony with the precious city arcades, in line with two existing ministerial buildings of Financial Offices and Civil Engineering and inserted at the <<tip of the feet>> as the architect Morelli would say, next to the XVIII Dicembre square"[9]. [5] This building due to its way of conceptualization is very significant example of the exceptional architecture in the years (60-70). The project execution phase was carried out by architect Morelli since Morbelli passed out in 1963.

[9]. [5]

2.1.1. Chronology of design-build-operate-abandon and reuse phases.

In this section are represented the most significant dates that brought life to this project. The study is made to show the complexity of the situations and the difficulty of decisions that were made during the process of building construction, especially in contexts like the one of Turin. Turin is a city with precious historical value where the preservation is central. The selection is initially extracted from the dissertation of an architecture student that was published in the year 1978 and focused on all important events of skyscraper's building. [6] The data was provided from the Central Library of Architecture "Roberto Gabetti" and finally, some data regarding the interventions after complete construction was found in the Building Archive of the city of Turin.

Table 1 The table of design Milestones

The design-built project and its successive modifications in time.	
Concept design	**22-08-59**
Final Design: Office building of 17 Floors	**10-03-60**
Completion of construction	**1968**
Operation phase	**1968-2016**
Plant interventions	**1979-2014 periodically**[10]
Emergency scales intervention	**1984**
First problems regarding health	**1992**
Abandon	**2014-present**

Below a chart represents better the extension of all these phases which are later described in detail. This table is further exploited in the next pages. The references (Ref.) are available for consultation only in the Central Library of Architecture in Turin, in the dissertation project aforementioned.

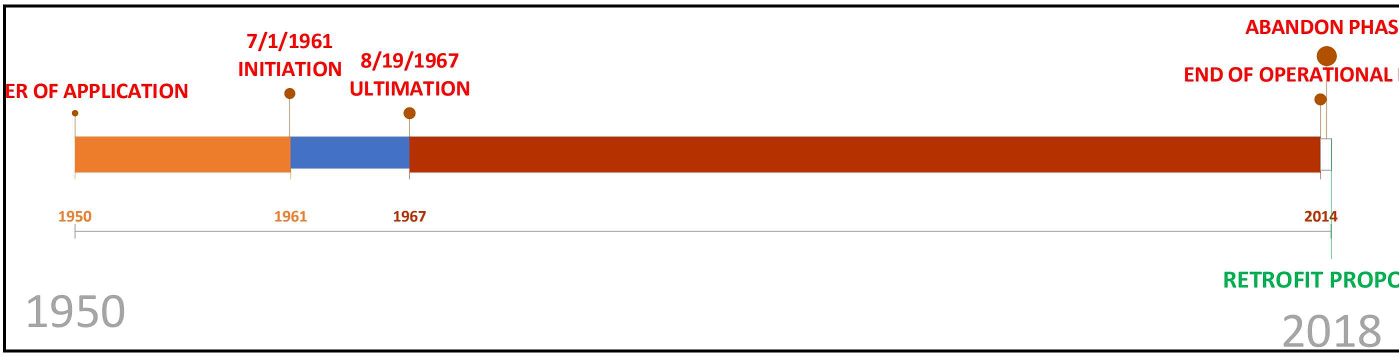


Figure 17 The timeline of interventions spread in 68 years

[10] More information can be seen in the "construction archive of Turin" (Archivio Edilizio della città di Torino)

Table 2 The long pre-construction phase of the complex

Date	Source	Event	Ref.
		Pre-Construction Phase	
1950	**RAI-C.C.**	Letter of application for a municipal area in order to build an office building	1
23/12/1955	**RAI-C.C.**	Announcement of the site purchase [11]for in via Cernaia	3
9/1/1956	**C.C.**	Announcement of the approval of the contract written in 23/12/1955 in the municipal union 46 total 40 yes 6 abstained	7
30/03/1956	**RAI-C.C.**	Announcement of official signing the site purchase for in via Cernaia	11
Nov-56	**D.Mor.**	Announcement for chargning Morbelli as the architect that will study some proposals for building design	23
25/07/1957	**RAI-C.C.**	Official letter for the demotion of the site purchase from RAI directed to the Torino Municipality	24
8/7/1958	**Quot.L.S**	Substantial modifications of the RAI project the building is seen as an exception from the PRGC	40
25/07/1957	**C.C.**	The demotion of the site purchase is accepted from the Municipality	44
17/02/1959	**RAI-D**	Official charging of two architects Aldo Morbelli and Domenico Morelli for the building	61
Mar-59	**P.D.**	Sketches of the facility made by the architect Aldo Morbelli for the Preliminary Design	0,0
11/3/1957	**D.**	Official request for the documents regarding the context around the building from Domenico Morelli	62
Jun-59	**P.D.**	The final Preliminary Design	0,3
5/10/1959	**RAI-C.C.**	The construction of the skyscraper is approved by the council in exception of the R.E	68
10/3/1960	**C.C.**	Announcement of the approval of the municipal design by the municipal council	73
29/10/1960	**C.C.-RAI-G**	Grant of the building permission a communication letter	86
28/04/1961	**P.W.**	Communal survey of the intervention area	87
21/07/1961	**Com**	Initiation of the construction works	88

[11] The contract of vending is found in the archives of Turin Municipality and has an interesting clausula which is still in force. The mayor of that time Amedeo Peyron had a futuristic vision and did not wanted to see the inventions flee from its city, so he made a foxy move in the agreement. The contract foresees a return of 50% of the value to the Municipality in case the RAI group sells it or changes its destination of usage. For more information and other specifications the document can be seen in the archive of Turin City.

Table 3 The construction phase of the complex

Construction and ultimation phase			
15/01/1962	**D.**	The elevation project	0.16
01/71/1962	**RAI-C.C-P.D.**	Report of the lower bodies	92
8/2/1963	**Quot.L.S**	Death of the senior architect Aldo Morbelli	97
30/04/1963	**C.C.**	Proposals for extension of the deadline of construction	99
9/10/1963	**D.T.**	The scales in concrete	0,28
18/03/1964	**D.T.**	The building façades	0,31
15/04/1964	**D.T.**	Particular drawings of the external components	0,36
9/12/1964	**D.T.**	Particular drawings of the air conditioning system	0,40
30/1/1965	**D.T.**	Variants	0,41
15/06/1965	**D.T.**	Particular drawings of the arcade	0,54
7/10/1966	**D.T.**	Particular drawings of the internal components	0,64
20/12/1966	**Quot. L.S.**	The ultimate RAI building with the picture	105
20/08/1967	**D.T.**	The insertion of the Mastroianni sculpture	0,71

Operation Phase			
1968-2014	RAI	The building is fully functional, in **1994** the first problems regarding the health of workers emerge due to the new legislation in the building safety measures[12].	
Abandon Phase			
2014-NOW	RAI	The building has no employees only a security guard and the building manager that takes care	
Design Proposals for a New RAI Office Building			
2018-NOW	PoliTo	A study for the requalification of skyscraper is in progress with a particular focus on the energetical issues	

[12] The legislative decree 19 september 1994, n. 626, (The new building safety measures updated to May 2018 can be further explored) [42]

2.1.2. Evolution of design in time

From design to the construction many things change, the circumstances vary, and the requisites may not be the ones of the starting point. This transformation will be represented in two different stages: Initial, how it meant to be and final how it has really been constructed.

Initial concept

As it occurs with most of the projects, the first requirements are almost always changed due to the client specifications, so the first idea of how it meant to be is quite diverse to what happened to be realized. It has not been easy, since it was located in a neuralgic point of interest for the city. As the sketches show, the designers had a lot of ideas on paper initially represented in the figure below:

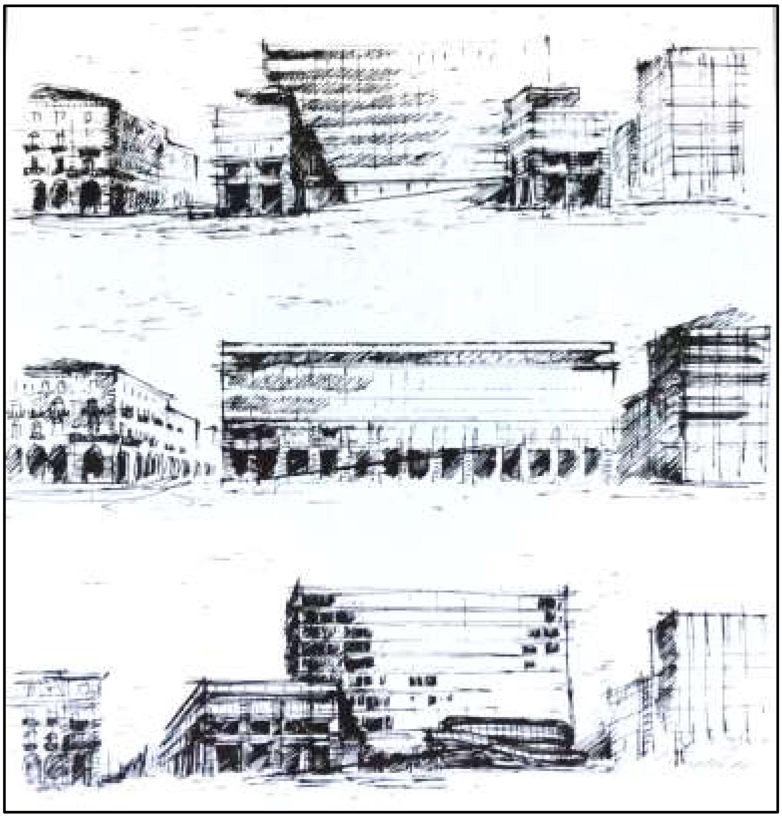


Figure 18 These are three sketches viewing the object from the square in front, representing three similar concepts.
SOURCE: Biographical book.

The initial idea was the building of a simple parallelepiped object, with an internal courtyard and sides of similar heights, this way it respected the municipality requirements and the regulatory plan. Due to the client requirements, this solution was not accepted, and it had to be reshaped. The request to accommodate 900 employees was challenging and the successive solution had to be thought carefully, thus compromises were made. The internal courtyard had a reduced area and the aesthetics and hygiene of the complex was a little bit compromised, but the final solution proposed by the architects surpassed every expectation while satisfying the client requirements.

The idea evolved into a more definitive one and the sketches progress to look more like the final design of the corner between Guicciardini and Fratelli Ruffini street.

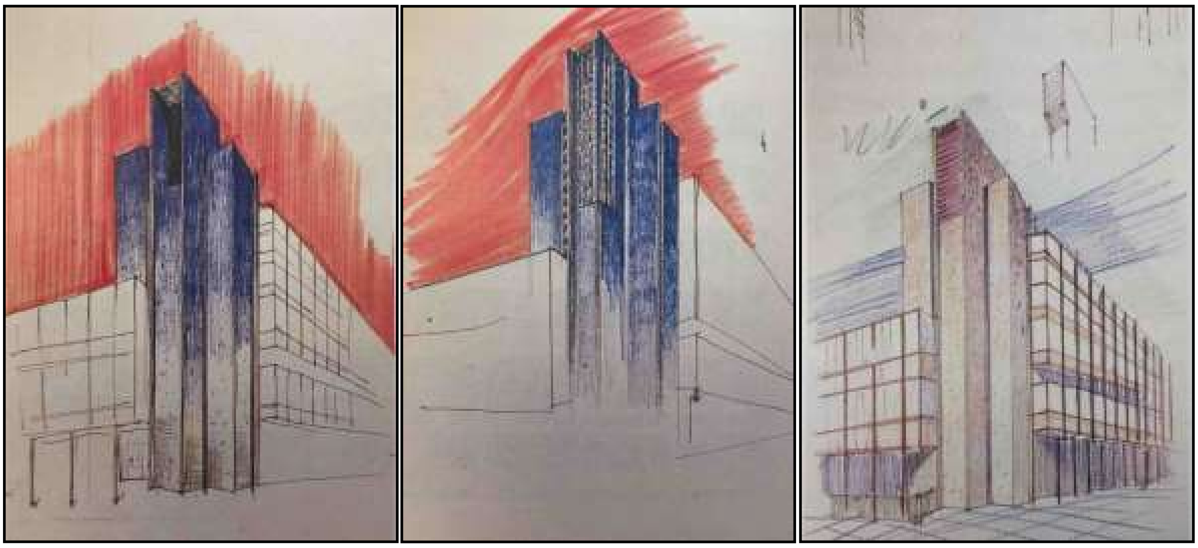


Figure 19 The evolution of ideas for the corner of Fratelli Ruffini and Guicciardini street
SOURCE: Biographical book

As it is seen from the above sketches in the table, the object has been in a continuous change, reaching in the end the right compromise between the different parts.

Figure 20 The sketch which has the concept as the final design
SOURCE: Biographical book

This figure on the left represents the idea of surrounding the building with four smaller bodies of the same height and maintaining the arcade in via **Cernaia**. The inspiration for the skyscraper design, as is stated in the biographical book of the author Morelli[13], was found in the Mies van der Rohe Seagram building. [7]

Finally, as it will be illustrated in the "Final Design" chapter the model left space to a more innovative and satisfying complex which would satisfy better the requirements of the client.

The most important aspect for the architects was the insertion in the existing context. The points that they firmly held: "Creating a complex that would represent the new functional and technical requirements; putting a building in via **Cernaia** that would fit in the composition of the road; elevate inn front of the square XVIII Dicembre an element of considerable height, that would create a separation but in the meantime would constitute a joint element between the row of the old fabric with limited height of via **Cernaia** and San Martino Square and the new state buildings in corso Bolzano, an element that is seen as join between the skyscrapers of the directional center and the old traditional fabric; containing the architectonic lines in the limits of maximal simplicity"[14] can be considered as a long lasting success as we notice nowadays. [8]

Figure 21 The insertion in the urban context in a harmonious way.
SOURCE: Google Earth

[13] D.Bagliani OAPT. *Domenico Morelli Ingegnere Architetto,* Torino, Toso, 1994. P.222.
[14] R. Pedio, *Grattacielo Rai Via Cernaia 33,* Torino, 1968, p.218

The view that this structure offers, can be enjoyed from many different angles of the city, some sights from particular spots in the area show the cautious imponence of this endeavor:

Figure 22 Spotted: The different angles and distances show the insertion of the skyscraper in the existing context. SOURCE: author

The detailed map with scale and orientation is represented in the Attachment

Final design

The designers proposed a skyscraper on the square, appropriately backward, to reduce the heights of other bodies in even lower limits than those provided by the municipal resolution. In the skyscraper were planned all offices and services of a normal nature and the particular services were placed in the lower bodies. Even though this project was in derogation to the GRP, it was approved in the competent office. This final mockup resembles the current facility. [8]

Figure 23 The mockup which better resembles the reality
SOURCE: Biographical book.

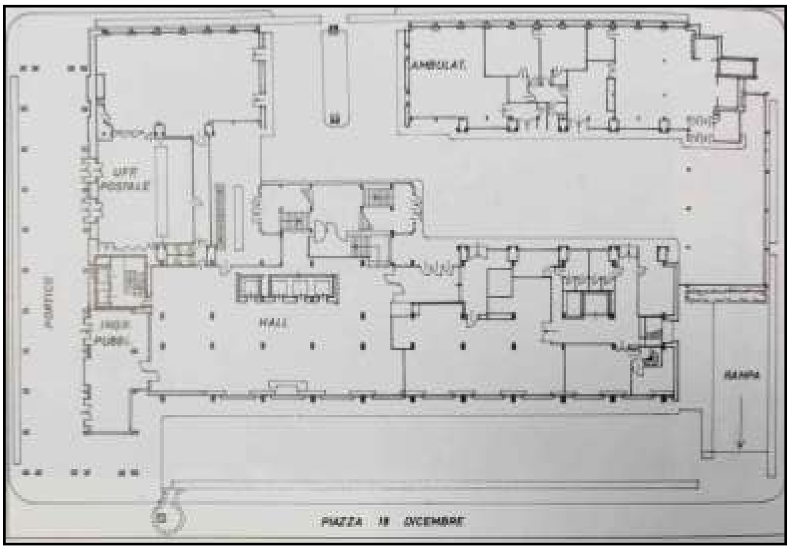


Figure 24 Ground floor plan with the entrance indication
SOURCE: Magazine "Guida all'architettura moderna"

Even though it did not bear a resemblance of 100% it is closer to the final construction. The metallic skeleton is visible. In the tower it creates a grill that encloses façades entirely in glass, while in the lower bodies the façade continues with another pattern and the transverse beams protrude to encompass the columns. The tower is connected vertically by a block of elevators in the hall and by a double scale that behaves as an independent volume and occupies part of the courtyard. An element of considerable interest consists of this double external staircase, detached from the body of the offices and connected to it by «bridges», on each floor; on the sides of these bridges the floor toilets are arranged. The double staircase is enclosed in a curtain-wall covering, like the one covering all the bodies, and is designed for a quick and ordered dislocation of the employees of the building. The columns of the arcade are covered in stone and bound by iron crosspieces.

The entrance is designed to be in the angle between via **Cernaia** and piazza XVIII Dicembre, a glazed compass extends into the arcade.

Beside is represented a longitudinal section of the complex and the first-floor plan, to create an idea of the relationship between its distribution and elevation to illustrate the description made in the paragraph before. In the next section these features will be further represented in different layouts.

In the lower bodies on Via **Cernaia** whose prospect is represented in the next image, are situated the canteen, the bar and the kitchens and in the one which faces via Guicciardini the plan foresees a mechanical center that occupies part of the courtyard, with an enormous hall elevated in the first floor, enlightened with natural lights.

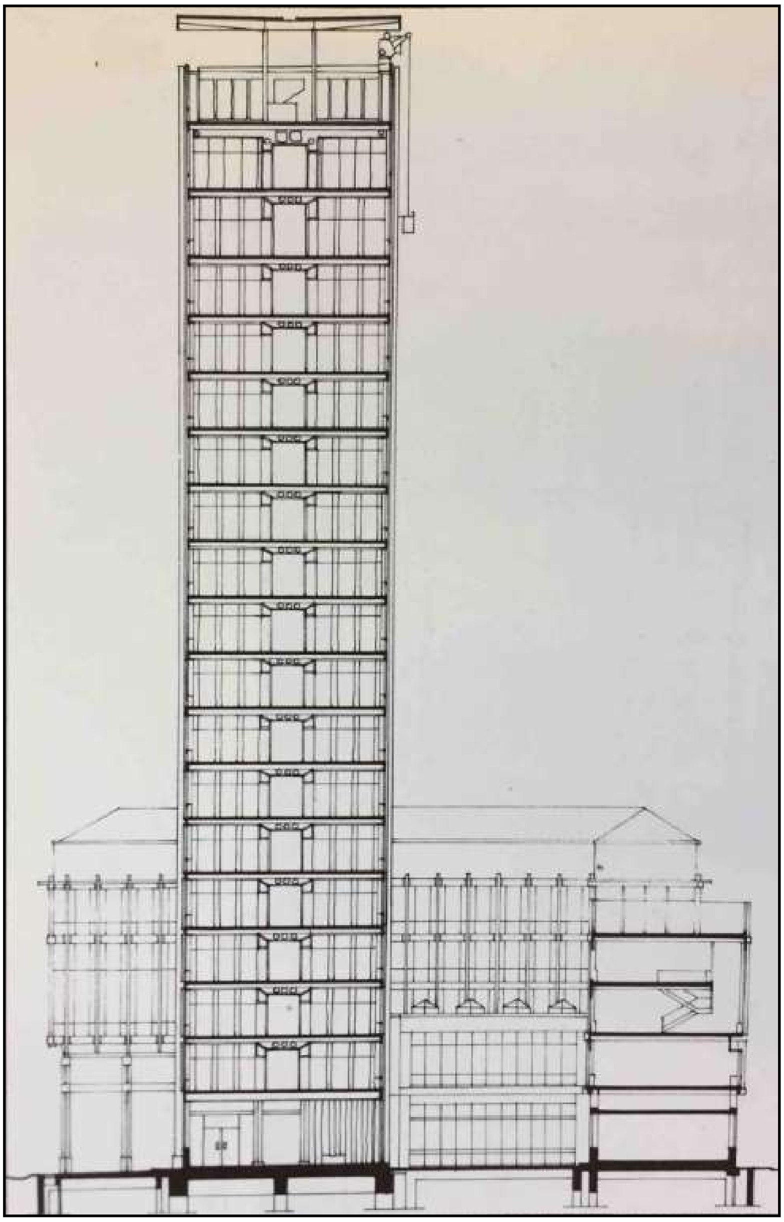


Figure 26 Longitudinal section of the skyscraper
Source: Biographical book

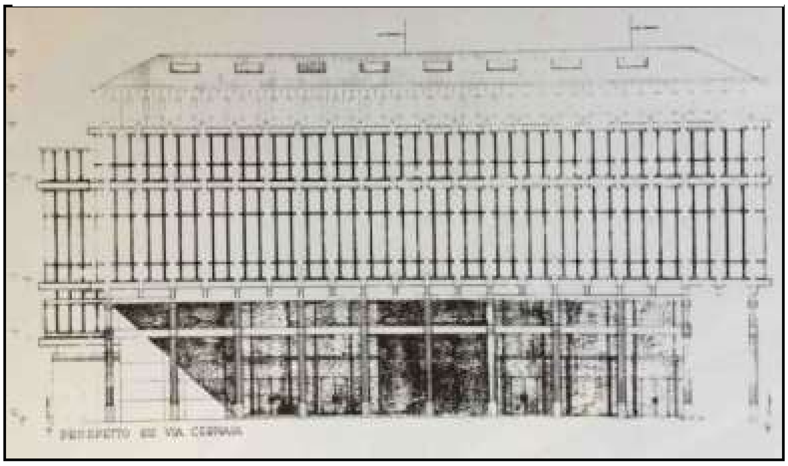


Figure 25 Cernaia avenue façade
Source Biographical book.

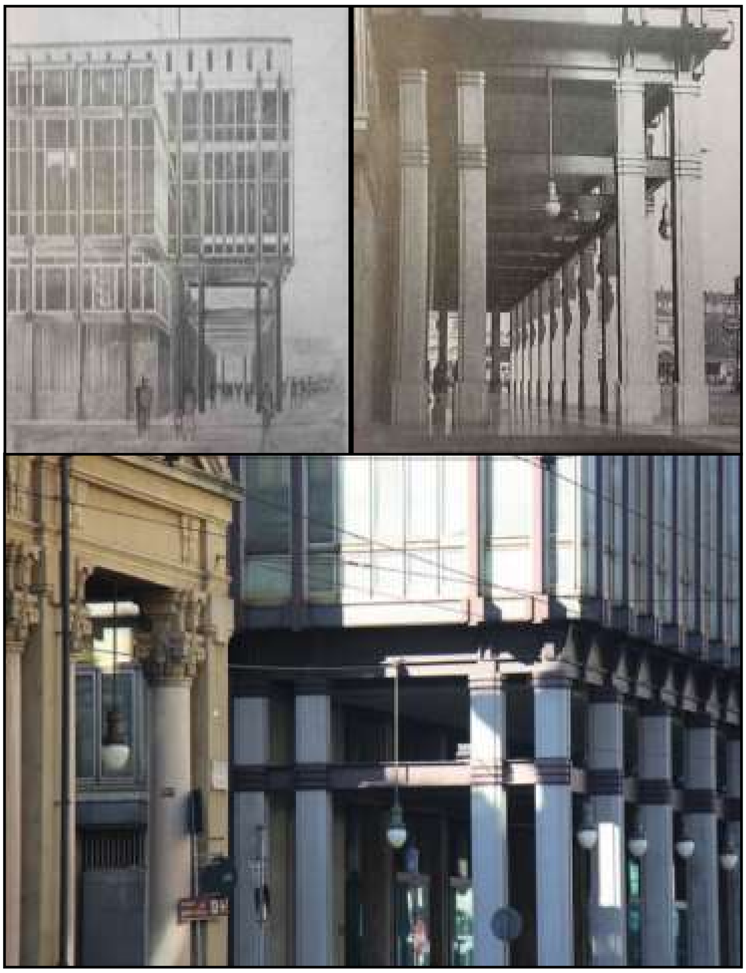


Figure 27 Rrepresentation of the final design 1 and the built part of the arcades 2 together with the existing situation 3.
SOURCE: Biographical book 1, 2 and author 3

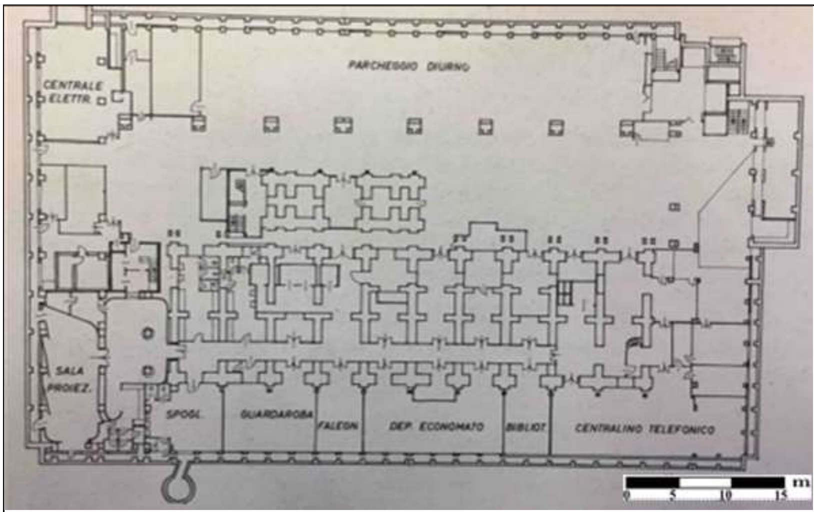
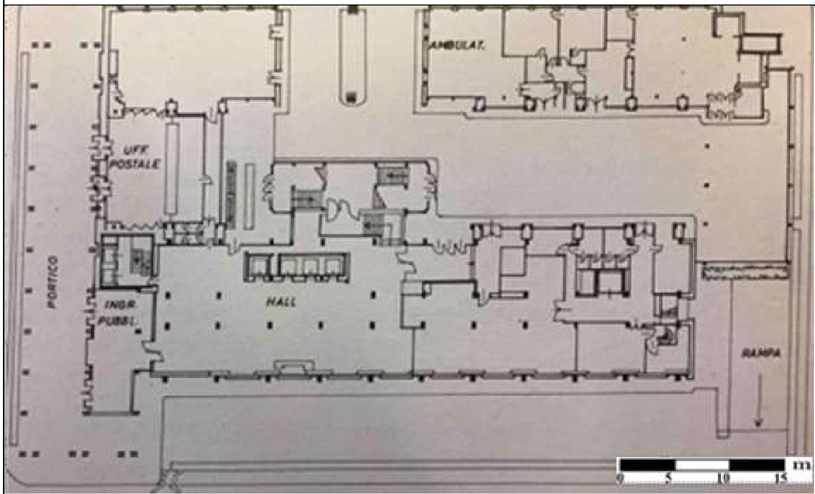
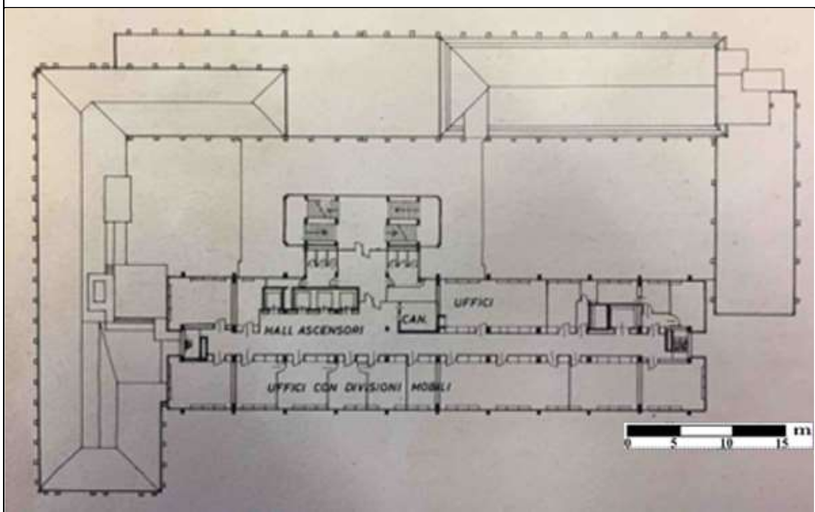
It can be noticed from the third picture the attractiveness in execution and the repetitive character of the columns which seem like the evolution of the traditional arcades. From the contrast in the side picture is perceived this evolving process, where the old arcades leave space to the new ones in the same street, in an articulated way.

Figure 28 The symbol tower
SOURCE: author

The final product is an rising tower in the square like a flag, with harmonious lines and exceptional modularity, becoming a symbol of the city.

2.1.3. Original functions and properties

This rare floorplan designs, represent the buildings original functions and properties.

<table>
<tr><td>
</td><td>Underground level
Parking lot
Telephone central
Library
Department of bursar
Carpentry
Wardrobe
Dressing room
Projection room
Electrical central</td></tr>
<tr><td>
</td><td>Ground floor
Public entrance
Main hall
Post office
Surgery</td></tr>
<tr><td>
</td><td>Typical Plan
Offices with removable divisors
Offices
Elevators hall</td></tr>
</table>

2.2. The structure of skyscraper

The building structure is a mix of concrete and steel with the steel as dominating material used mostly in the pillars and slabs, to permit the long spans. This ultimate characteristic can be very useful in a possible future intervention on the facility.

2.2.1. The foundations and elevation structure

In the following scheme is illustrated the frame of the building. It contains the major scheme of the foundations and the body of the elevation structure together with the roof cantilever structure.

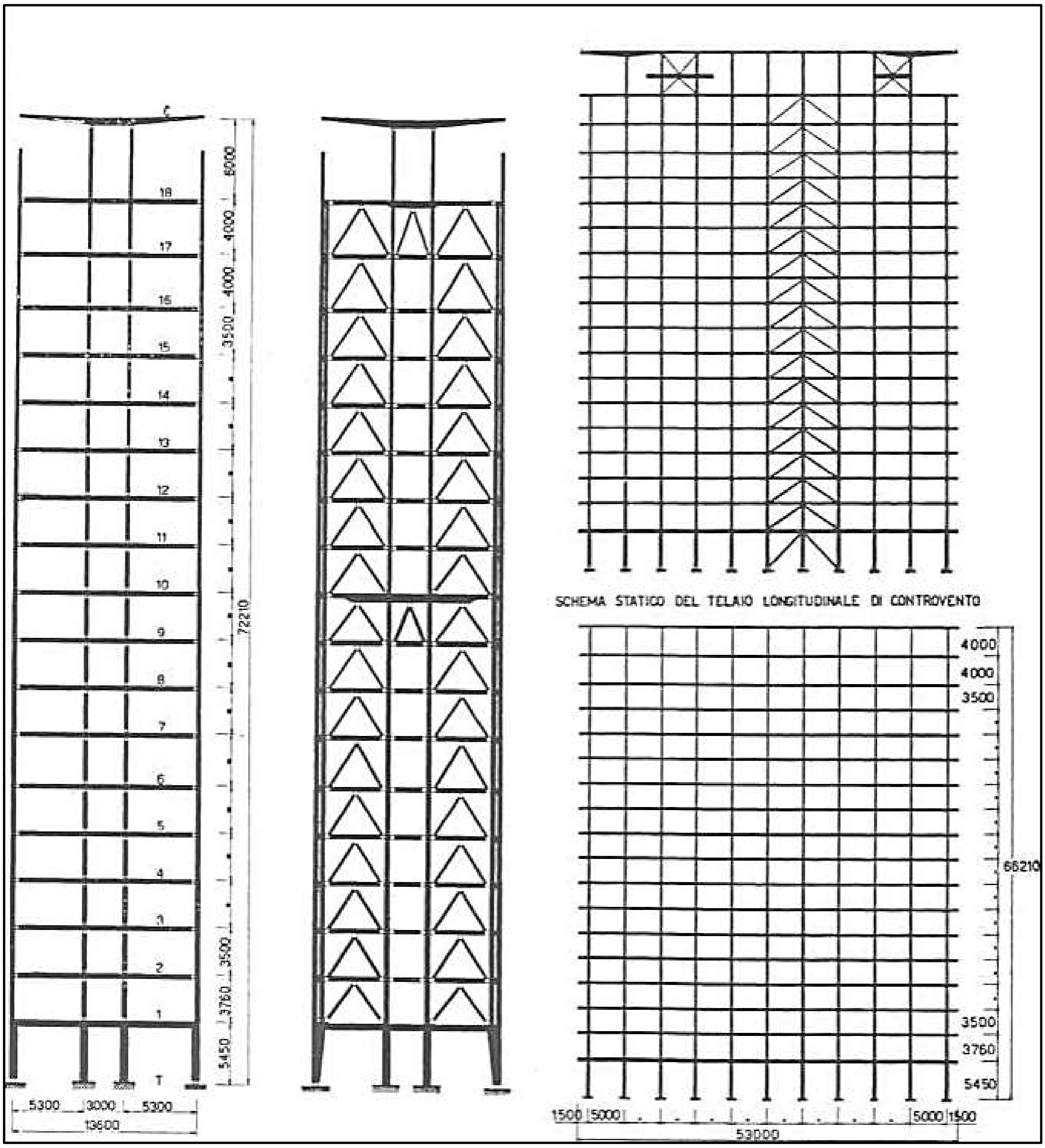


Figure 29 The skeleton frame together with details and the static scheme of its functioning
SOURCE: Un nuovo palazzo a Torino RAI.

2.2.2. The metallic skeleton details

The metallic structure of the skyscraper has a regular disposition and is represented below in plant with the technical specifications and quotes. The grid of the columns is modular of 5 meters in transversal direction, while in the longitudinal one, it has two modules of 5.3 meters and one of 3 meters.

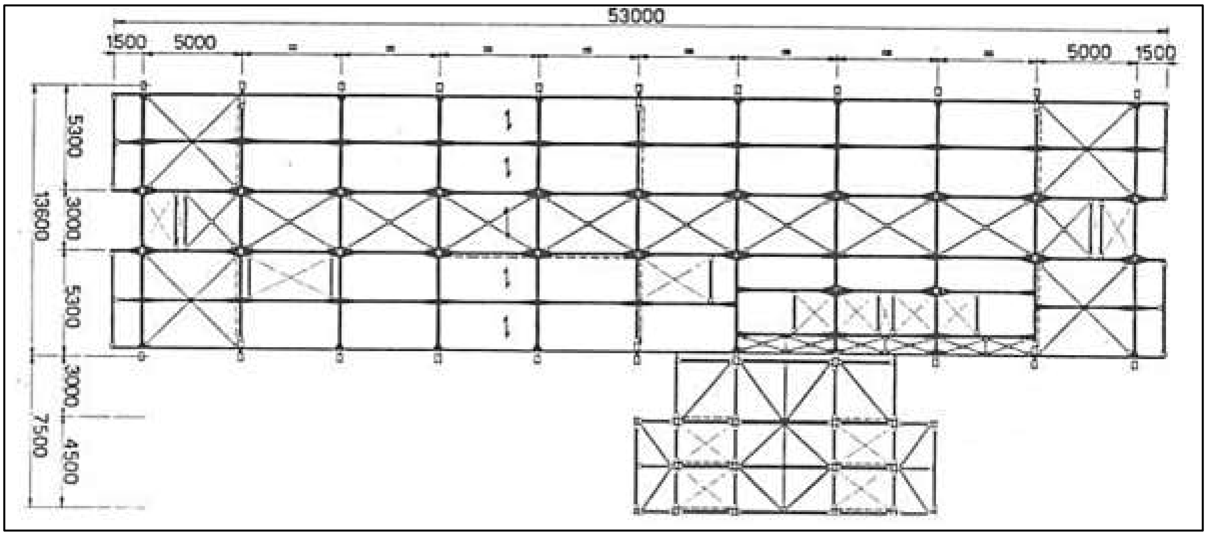


Figure 30 The plant of the skyscrapers structure.
SOURCE: Un nuovo palazzo a Torino RAI

These four lines of columns determine the structure of the skyscraper. In order to absorb the stresses that come from the wind horizontally, three transversal diaphragms and one longitudinal are designed. They absorb the wind spin using the slabs, a force that is predicted to support a wind speed of 150 km/h in the façades. The diaphragms as is seen in the figure below are anchored in underground structures made of concrete.

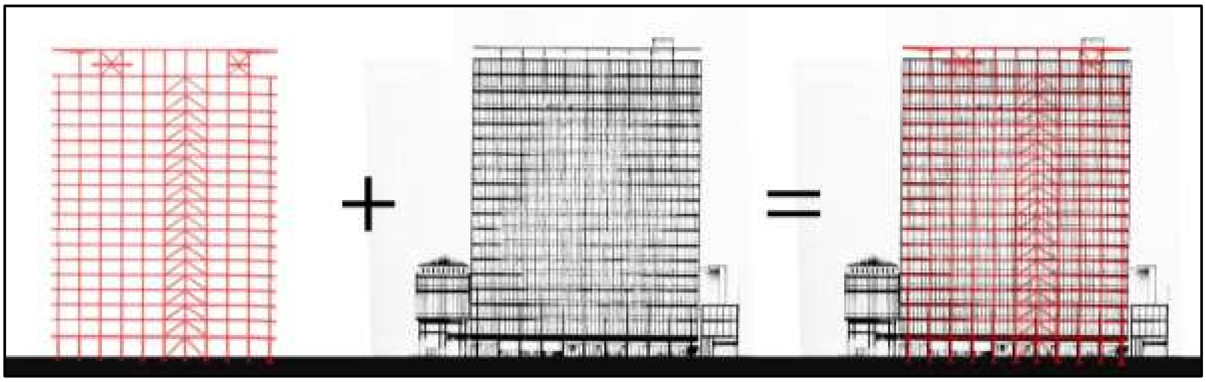


Figure 31 The main structural scheme of the skyscraper with the wind braces.

2.2.3. Connection details and type of components

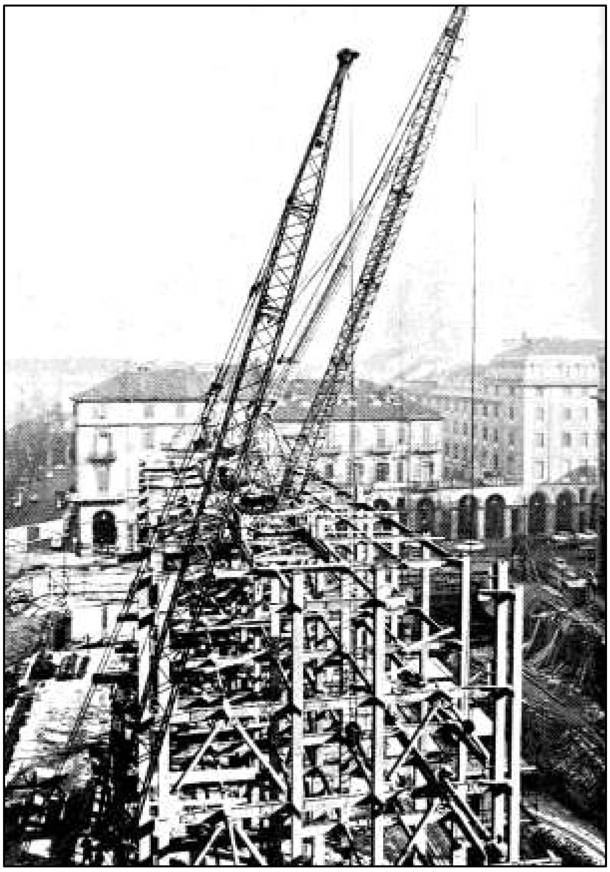
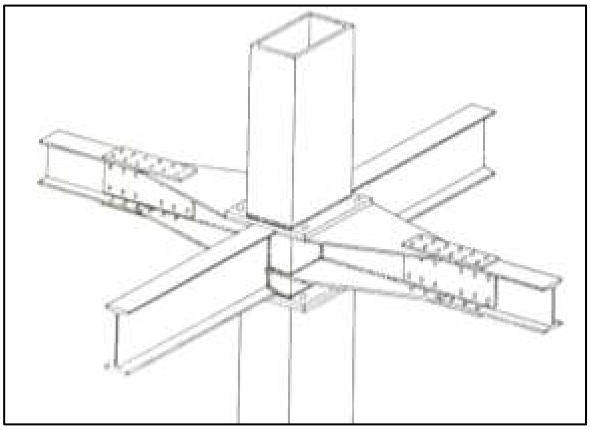


Figure 32 The metallic frame under construction.
SOURCE: Un nuovo grattacielo a Torino RAI

The beams have a double T section. In the lower levels the perpendicular beams to the external walls are made of two C sections separated and inverse, cutting out the façade and connecting the pillars in a way that a buttonhole large as the pillar continues and allows the vertical pipeline systems.

The horizontal parts are made of trapezoidal sheet metals in which lays a slim slab of concrete. In this figure is represented the junction between an internal pillar and its beams. We can see the use of two techniques of connection, welding and bolting of the different elements.



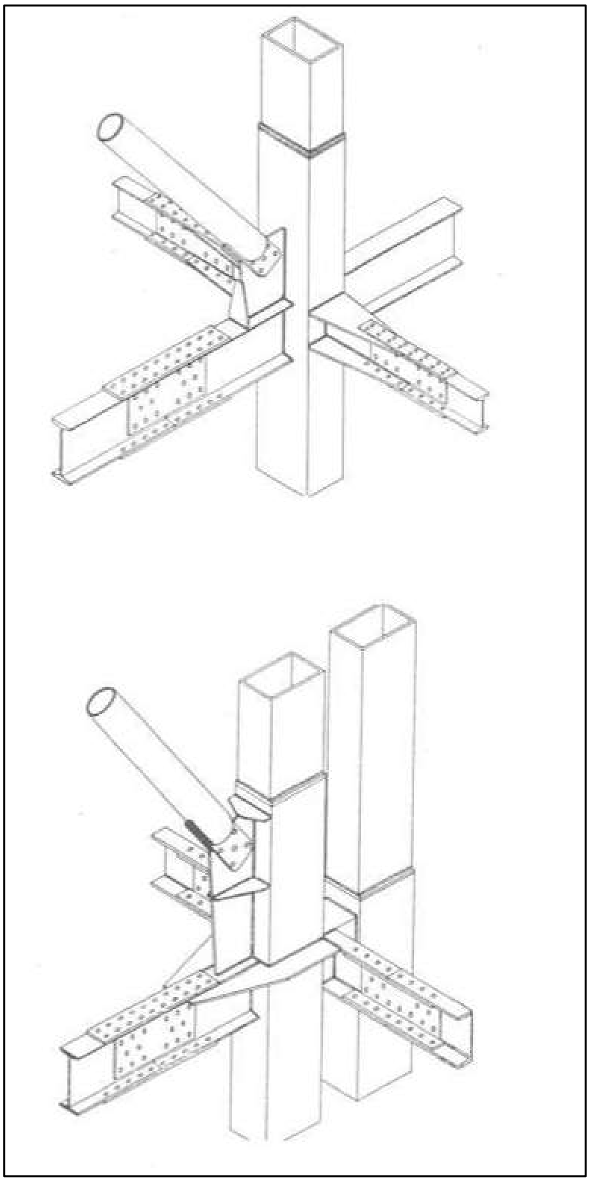


Figure 33 Connection details in the internal nodes 1 and wind braces 2,3.
SOURCE: Tesi di Laurea Giorcelli

2.2.4. Actual state of the structure.

From the information obtained from the RAI internal studies, the structure satisfies seismically the requirements. On 09/10/18 an ultrasonic test (a non-destructive method in which high frequency sound waves are introduced into the material to be examined, in order to highlight surface or internal defects, measure the thickness of the materials, measure the distance and the size of the defects) was finalized on two pillars of the structure in the locations assigned in the plant below:

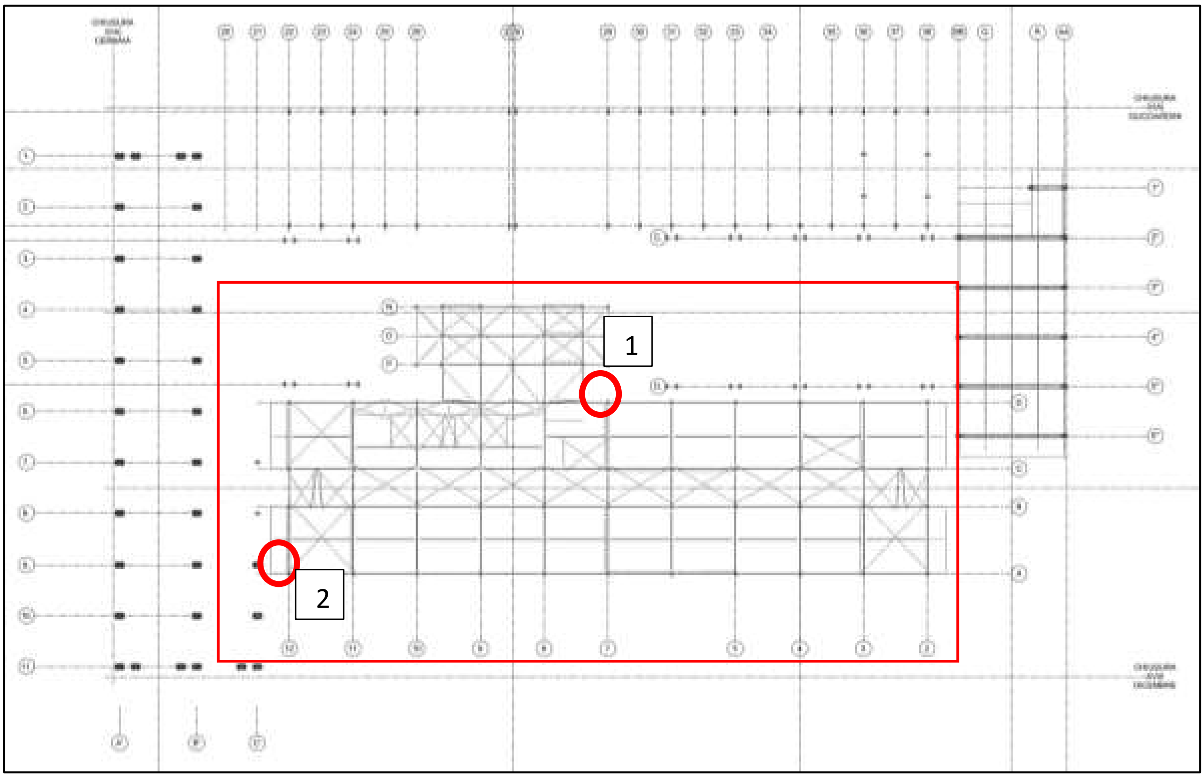
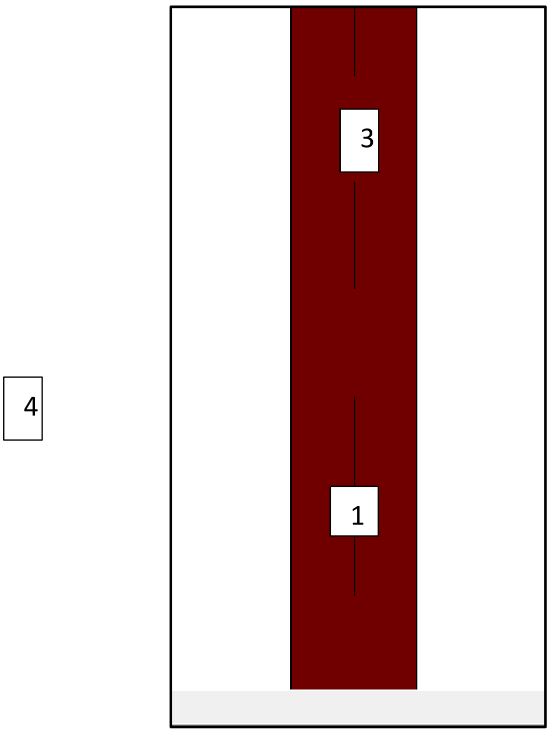


Table 4 The results of the ultrasonic test for structure reliability



Position	**Measure (mm)**
1	29.67
2	25.7
3	30
4	24.12

These measures are relative to the first pillar in the plant and confirm the reliability of the structure. The only intervention needed to be made regards the fire protection measures for the metallic structures.

Figure 34 Position of the measures in the pillar of skyscraper

2.3. Systems

2.3.1. Generalities

In the moment when this building was constructed the energetical and environmental problems that we are facing today did not exist. The combustion fuel was an unlimited source and the costs were negligible to the current one. Some generalities follow below, from the company that designed and built the conditioning system.

The main conditioning system an induction one. It goes from the first floor till the 16th.For the offices in 17th floor is built a double-duct system. The air conditioning system is with low speed and different zoning on the air supply. This system is integrated with radiant panels in the ceiling on the ground floor. The restrooms had radiant panel heating systems and air extraction system. There was also a thermal power plant and a refrigerating plant.

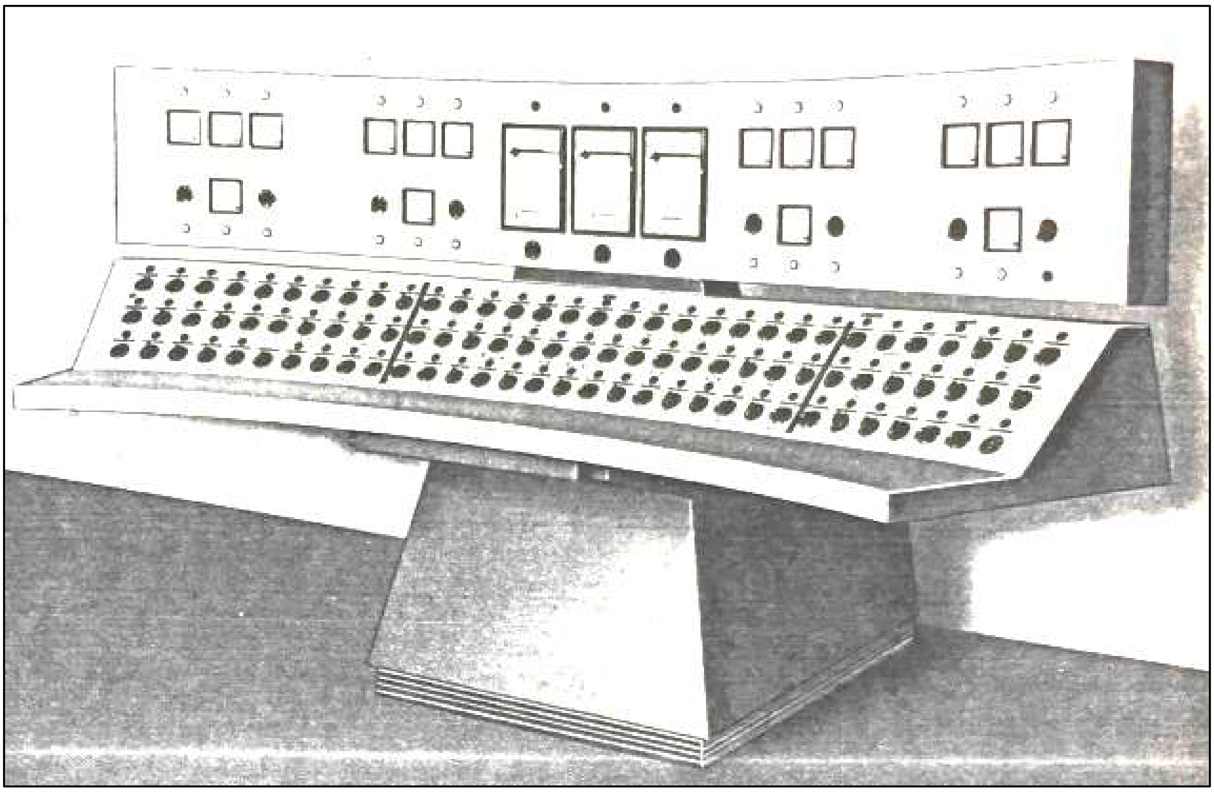


Figure 35 The control panel of the facility. SOURCE: Master's thesis Giorcelli

2.3.2. The skyscraper induction conditioning system

Given the modular construction of the building with internal removable divisors and the homogeneity of the thermal loads from first till 16th floor, the designers proposed and built an induction conditioning system composed of two tubes. This system fits perfectly in this building layout. The air supply of primary air is 50.000 m^3/h all taken from the external air. The conditioned volume is around 22.000 m^3.

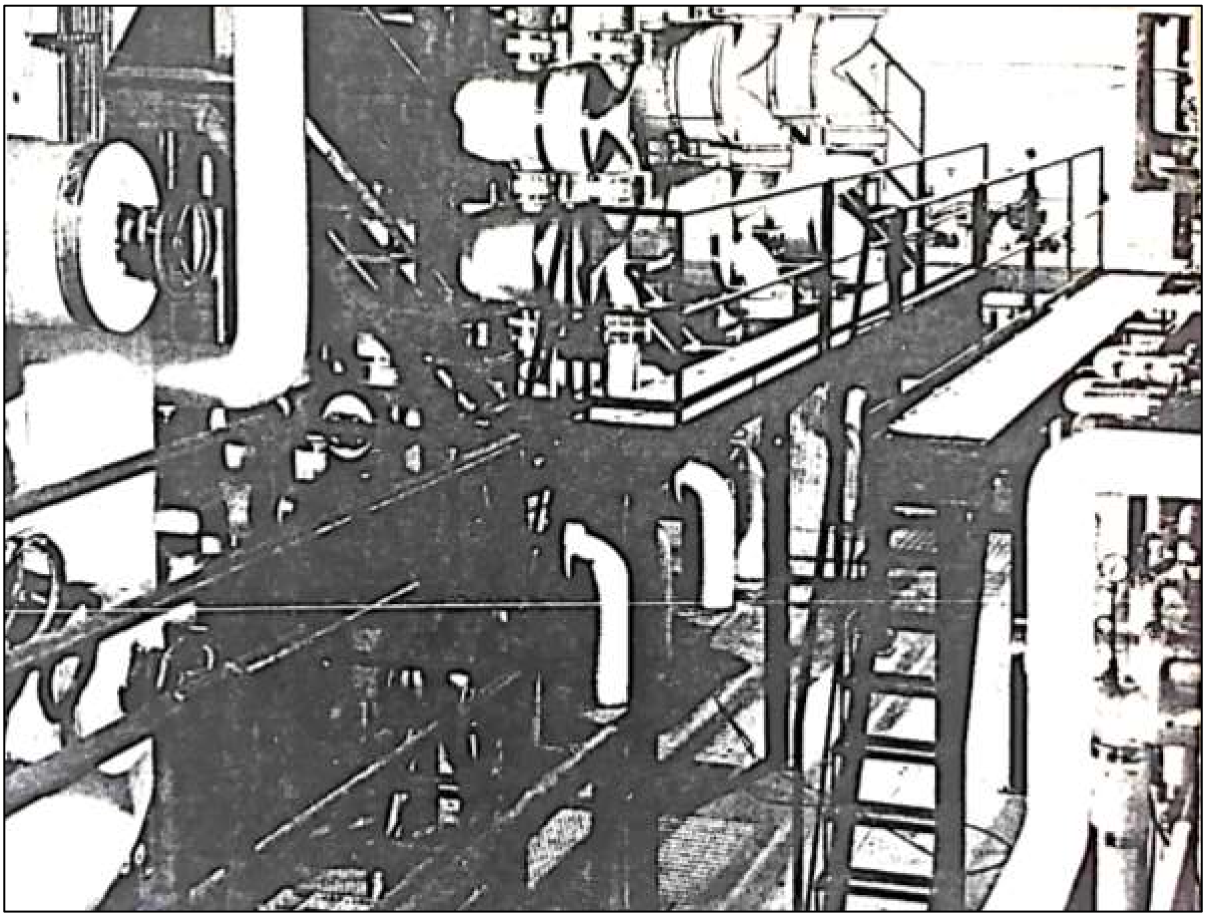


Figure 36 The mechanical components of the central heating system. SOURCE: Master's thesis Giorcelli

Considering that the two main exposures have periods of maximum insolation, during the daily operation, it was decided to separate the secondary water circuit. This choice was due to very different numerical values in the South East and North West façade especially in the periods in which occurred the seasonal switching. The goal was the limitation of operating expenses. The plant consists essentially of an air conditioner located in the power plant that handles the primary air and sends it to the local air conditioners, with circular section cabling, using the primary air as a motor of vehicle, treats the recirculating air resupplying it in the ambient and from a heat exchange system and electro pumps for the treatment and recirculation of the secondary water.

2.3.3. Summer operation

In this period the principal air conditioner, treats the air that comes from the outside and sends it to the terminals in a variable temperature that depends on the external temperature. The air first is filtrated and cooled down until 12 °C then post heated in a variable temperature from 12 °C to 30 °C. In the meantime, in the terminals is send water in a constant temperature of 13 °C during the whole summertime. This is achieved using a thermostat with a fixed value and a three ways valve in the primary system of cold-water supply. Since during the day the variation of the temperature is significant, the principal duty of the external air is the air renewal, the neutralization of the latent loads and that of heat transmission with the façade (positive or negative). The water flux in the terminals is regulated by thermostats placed in the ambient which varies in base od the sensible internal loads depending essentially on the radiation.

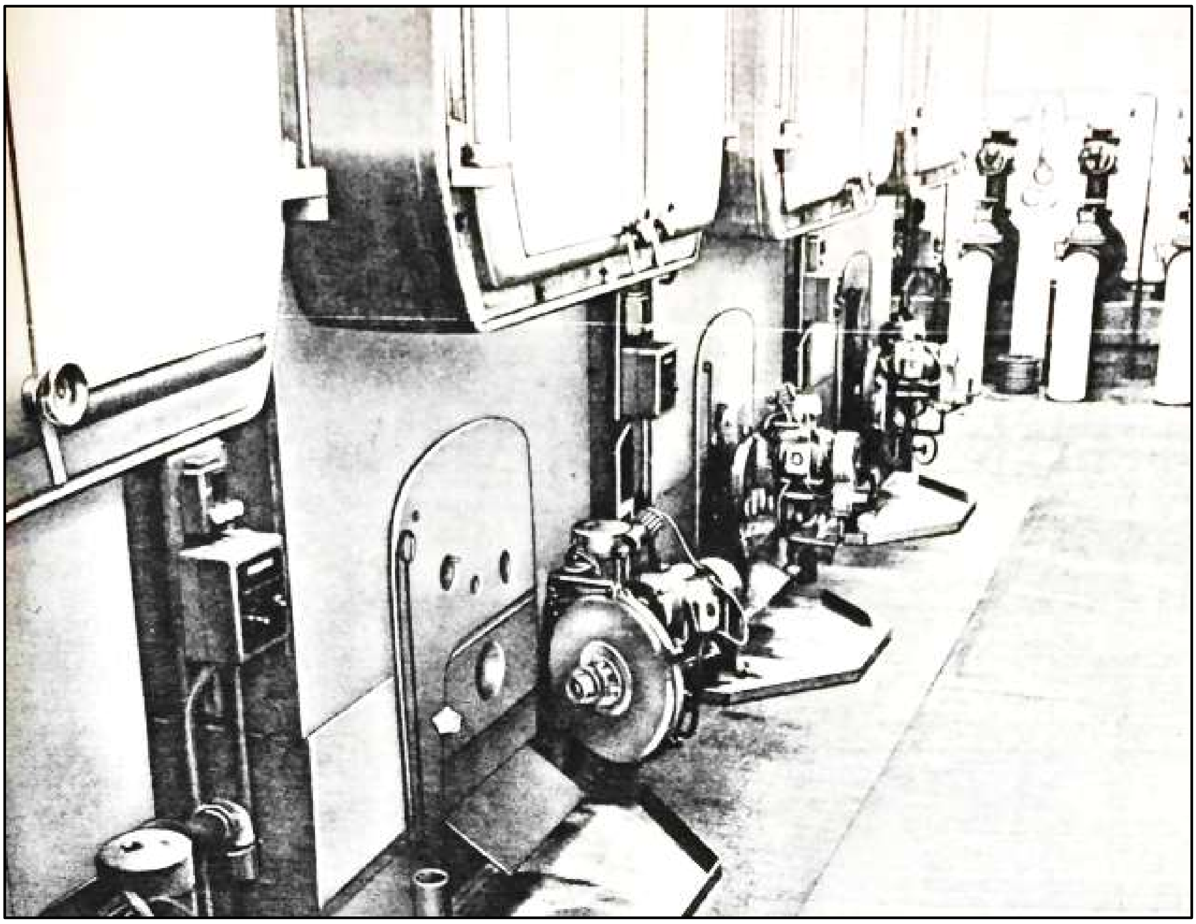


Figure 37 The pumps in the systems room

2.3.4. Winter operation

During the winter season the primary air treats the external air and sends it to the terminals in a fixed temperature. The air is filtered, heated and humidified until reaching a temperature of 12 °C and sent to the terminals where arrives contemporary the hot water. The battery of the local conditioning system, affronts not only the heating losses with respect to the external ambient, but also the post heat of the primary air. The supply air is the reason why some rooms have more losses towards the external ambient.

For example, in the sunny days, as radiation increased, the thermostat installed in the ambient decreases the water flux of hot water until its complete stop. Then it's the primary air itself that acts as a refrigerating fluid to neutralize part of the radiant load.

2.3.5. Dual functioning during winter operation

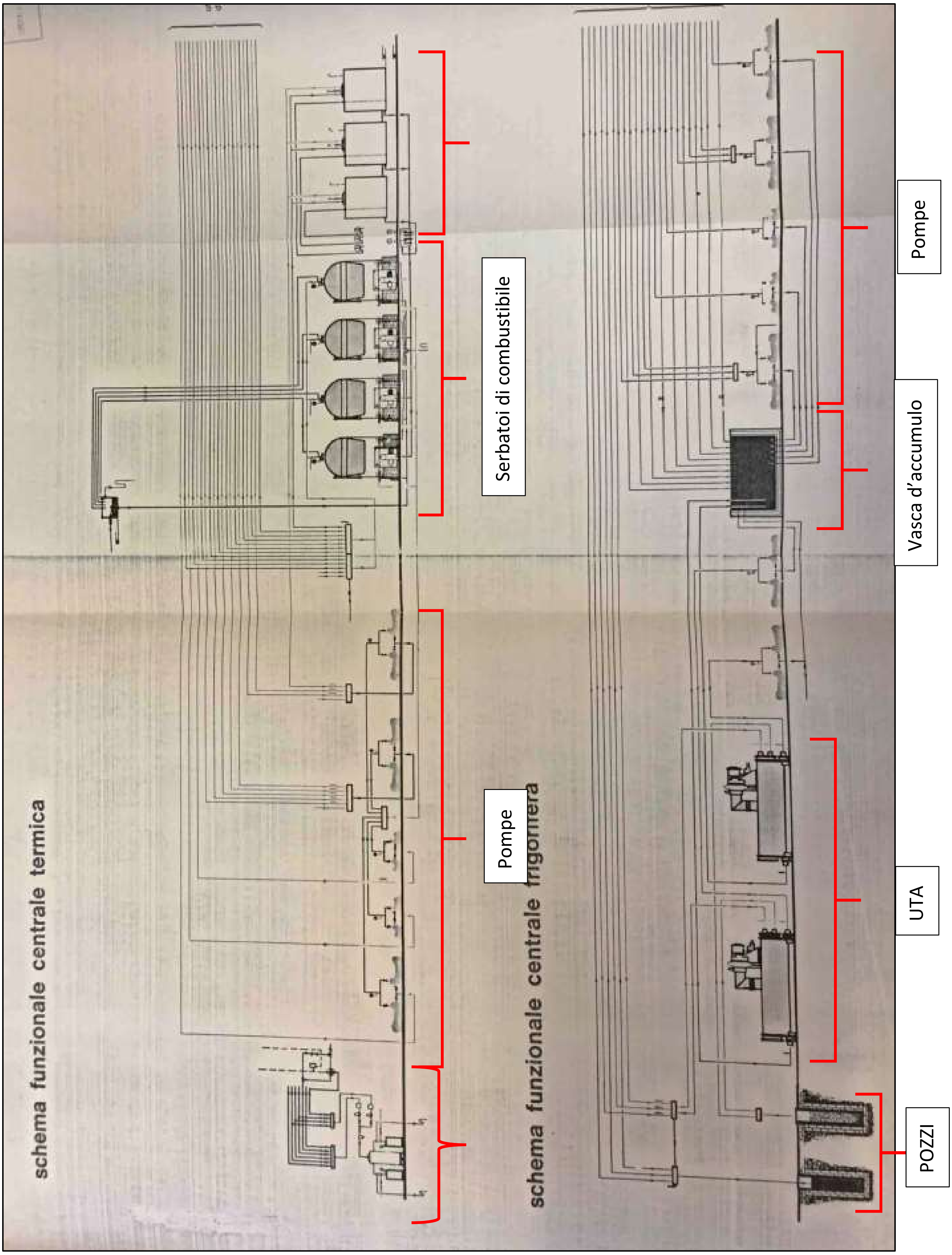
The peaks between two zones are so evident that in special days the external air cannot neutralize alone the internal loads. This is the case when the systems behave like in the summertime. The temperature difference between two façades is very different. Especially in the winter days the radiation values are very different, so the circuit of water is split in two. In this way the cold water can be supplied only on the part of the façade where the radiation is high where the supply air cannot cool down the internal environment. This solution is made by implementing an external Master circuit containing a solar compensator that reproduces the conditions of internal rooms with respect to the radiant effect and the temperature difference between the internal and external faces.

The animations show the sun radiation in the tower during a day from two perspectives. SOUTH EAST and SOUTHWEST

Scan me

Scan me

This mechanism starts to operate when the radiant effect is higher that the dissipations and the refrigerating effect of the external air. The thermostat calls for commutation in the interested zone at the heat exchangers that are in the central area, thus supplying with cold water.



SCHEME 1 Functioning of the refrigerator center and thermal one in their original state which is maintained also nowadays

2.3.6. The existing situation of the components

Figure 38 On the left of this picture is the canal of new ventilation system for the lower bodies

The existing situation of the systems seems generally good, with only some apparent defects that do not influence the overall functioning. The HVAC system components are renewed and replaced several times. This choice has come due to some changes in regulations and the need of the machines to be replaced. Particular attention in the future should be paid to the maintenance of these systems, especially the canals since it is the principal cause of the SBS.

Central heating system

The situation is almost exact as the one the engineers designed in the beginning. The thermal central has a total potential of 4800000 Cal/h divided in four boilers of marine type having each 1200000 Cal/h designed to heat up the water till 85°C. For the storage are predisposed 3 tanks of 16 m^3 each. The boilers are changed, but their potential has remained the same

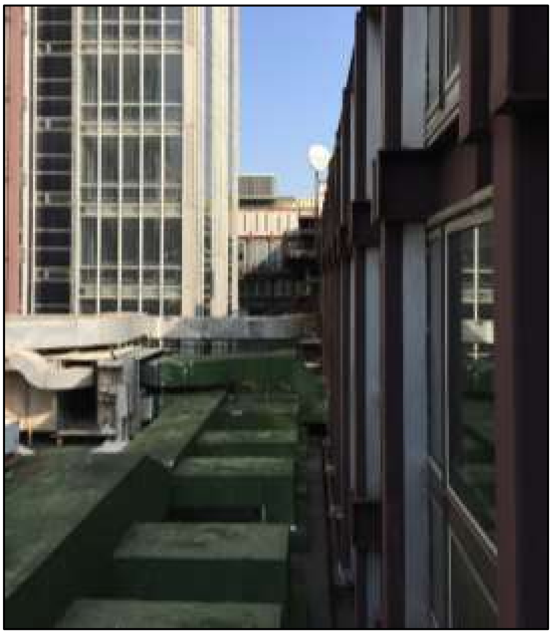


Figure 39 On the right is the old system, in green color

Central cooling system

The only change made is the addition of a new refrigerating group, that augmented the load to 3000000 Frig/h. The water produced from the refrigerating group, is poured and stored in a reservoir of 400m^3 capacity where is used for the necessities.

The cooling load is absorbed by the well water which is utilized in the precooling batteries with a flux of 200000 l/h is sent to the central conditioners with a peak of 4 °C.

The cooling load used by the well (pozzo) water with precooling are 800000 Frig/h so the total refrigerating potential can arrive at a 2800000 Frig/h.

Automatic regulation

The automatic regulation is of a pneumatic type for all the systems. In the conditioners are available sensor controllers and for the first time in Italy, the implementation of environmental thermostats of type Sub Master with distant inversion.

The fan-coil type and preservation strategy

Figure 40 The fancoil units

They have a particular type of machine which is regulated only by the thermostat and cannot be manually changed for each machine, that can be a cause of local discomfort. The advantage of this system is that they do not have ventilators and the maintenance is necessary only in extreme cases. This is an element that can be worth to be conserved in the future refurbishment of the building.

Figure 41 Window opening and the relative grill of the air flow from the air distribution units.

Conclusions

In the time where these systems were designed, they were mostly the first of its kind in Italy. The interesting part is that they have maintained the conditions as built, with little defects. Although obsolescence of the machines is a factor of time, the design and functionality remain unchanged and successful along the years.

2.4. The façade

The façade is the most characteristic part of the skyscraper since it encloses all the body in modular parts like the figure that follows:

Figure 42 The repetitive module of the continuous facade.
SOURCE: FONDO MORELLI

2.4.1. Classification of functional layers

The support layer

This layer consists of vertical and horizontal mullions and has the function of supporting the dead loads and those of the layers bound to it and the overloads due to the pressure or depression of the wind on the façade system and / or the loads due to accidental impacts on the inside or outside of the wall itself. This system coincides with elements being part of the subsystem of the building structures within which these vertical and horizontal structural elements are integrated.

The protective layer, coating and sealing

These three functions are carried out by the whole glass-frame of the façade, thus preventing rainwater and air infiltration from reaching the internal ambient. Moreover, this layer allows the isolation of the internal environment from external noises.

The connecting layer

It is composed of an integrated set of elements having the function of ensuring the connection between the supporting layer and the carried element.

2.4.2. The existing situation

Figure 43 The rotational opening of the window

The only part of the building which seems outdated the most and influences drastically in the overall energetical performance, is its enclosure. Its seen from the calculus chapter 3 that its substitution, will bring a high energy reduction need. The façade in its time was an avantgarde design, compared to the iron ones that were built in the city. Nowadays, as the pictures show, the conditions are obsolete. They show signs of degradation and the materials have lost their insulating and thermal properties, due to air and water leaking in many of them. It cannot be said the same for the aesthetics, although it has lost its shiny properties, the modular and repetitive character gives the building a graceful aspect.

Figure 44 Representation of the damages and degradation due to the leakage and harsh weather conditions.

2.5. Architect

In this section the principal architects that participated in the building of the skyscraper are mentioned and an analysis of the style of the crucial architect is made. It is important to understand the architect and make this analysis because in this way we learn a lot for the building, since it mirrors their ideas.

2.5.1. Domenico Morelli e Aldo Morbelli

(3/08/1900-26/05/1998)

Architetto sensibile al dibattito internazionale e al linguaggio innovatore del Razionalismo europeo, è autore di numerosi progetti in città prima e dopo la Seconda guerra mondiale, dalla casa di via Vico al grattacielo Rai.

(01 /08/1903 - 08/02/1963)

Architetto, tra anni '30 e i primi '60 si occupa di una vasta gamma di progetti, dal restauro all'urbanistica all'edilizia residenziale, per spettacolo e per uffici, in Piemonte, Valle d'Aosta e a Roma; è protagonista della vicenda della ricostruzione del Teatro Regio e della progettazione del grattacielo Rai a Torino.

The architectural style of Morelli

It is hard to define the boundaries for the style of this highly skilled professional, considering the variety of his works, the long timeline of more than 60 years and finally the way he used to live his life. He used to hang out with painters and freelancers, writers, gallery owners, all possible types of people. I would say that he was a man of his time and the projects he completed impose also nowadays a feeling of respect.

Morelli affirmed his activity in the year 1930 by building the first house (casa di via Vico), designed by modern criterions in a moment when the new art of modern architecture flourishes.
During this time, he works for the reconstruction of the first segment of via Roma, the most important work of demolition and refurbishment happening in Torino. Successively he participates in the competition for the second segment and wins it together with a team of other colleagues.
The proposal had rationalist ideas and maintained the arcade in both sides as a typical feature of the city. The result of this intervention produced a mix between the "mitteleuropean culture", the traditional piedmonts design and the presence of monumental taste[15].

In the year 1934 Morelli builds the house Tabusso, which is a prestigious house in corso G. Ferraris 95, with whom he testifies the affirmation of the rationalist architecture bonded together with some classical details, like the elegant symmetry of the façade and its division in basement, stem and crowning. The building is surprising for its unusual disposition, adhering to the fundamental needs of the modern residence with the two pedestrian ways and the caravan on the ground floor, the distribution of the rooms, the accuracy of the construction drawings. [16]

[15]L. Sasso. *Morelli nella cultura architettonica tra le due guerre*,
[16] *L'architettura italiana,* july, 1940.

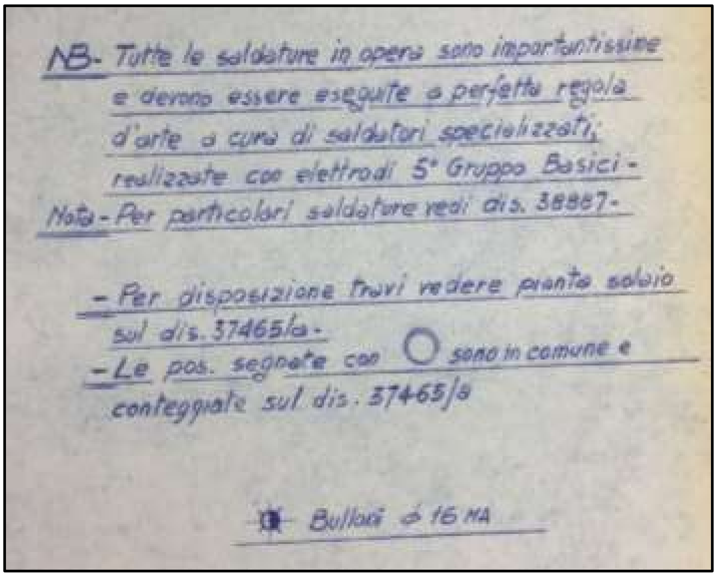


Figure 45 The way of representig until the last details some of his drawings. SOURCE: Fondo Morelli

He had a strong a belief in the "culture of living "and he was not influenced by the movements that dominated the design culture in those years. The situation in Torino has undoubtedly played a role in his favor, where the designer has maintained the culture of the built environment as: a living environment, a working environment, a curative environment, and an environment for the free time. Especially this choice distinguishes him from the post-war architects or the others of the next generation. Most important for him are the distributive schemes of the building, believing firmly that also the clarity, the strictness, the functionality of a distributive organization, the beauty of the clear organization in the floorplan, is a strong component of the compositional and formal values.

On the other way, like too many of his colleagues, he found it genial the creation of a well determined technological island, that could warrant a neutrality to the fantasy and personal choices.[17]It seems almost obvious that the constant sober compositional elegance of its buildings has its foundation on this choice. According to the above author, Morelli used to say always that it is very important to pay attention to the site trying to insert the building with the biggest caution. This statement is true for all his works where by instinct, he did not have the imponent ego to make shadow for the others work. From his fellow students, Morelli was a consolidated professional, who had been affirmed before the world war, producing an architecture that seemed attentive to the context, at the same time respecting the construction methods, adequate at the market requests, not obstructive, little exotic, so it was practicable, comprehensive and handy. [18]The "engineer architect" seemed to have understood the relationship between the materials and the space regulations. This brought a great respect for the current technology because it was used so professionally, and the young students followed this moral and professional role model with pleasure.

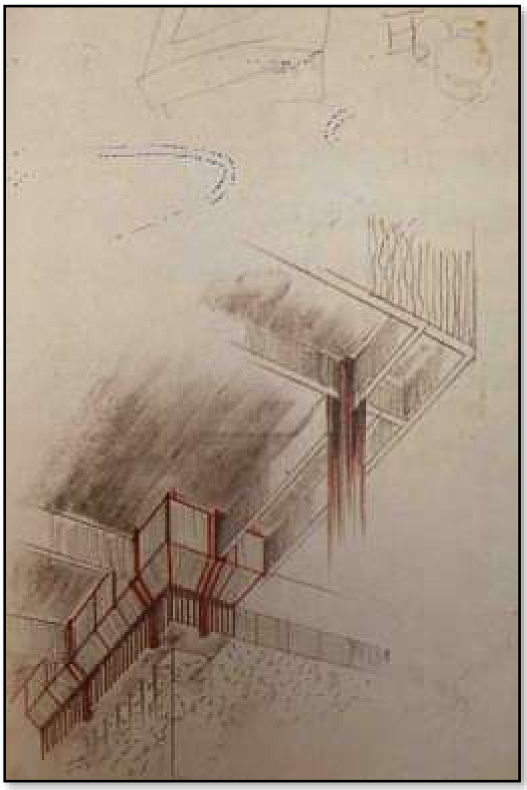
One of his colleagues Felice Bardelli, who accompanied him in the entire career has made the following description of his work ethics and personality:

"Closed with his theme in a kind of bubble, that does not admit distractions, where he tries to intuit simultaneously: the presence in the urban context like the distribution of the volumes, dimensions and forms, structural functionalities acceptable by all, or particularly able to satisfy an active commission, until the technologies and decorative intuitions able to define the building or the complex that is being designed. For Morelli the research has always been continuous and evolving, sometimes during the building process to reach a compositional homogeneity between all the elements that constitute the designed space". Obviously, this can be said for all the architects, but the particularity of Morelli was his cure of the construction details. As one of his collaborators says: "We have learned

[17] <<*Morelli libero professionista*>> P.G. Bardelli.
[18] <<*Morelli e l'edilizia degli anni '50 e '60 a Torino*>>, G. Torretta.

from the master that every line that you draw, not only represents something that the others will read, but it should be clear to you that it is very important to think about the person that is going to physically built what you feel, think and translate in the paper. The respect for the human labor has the same value, or more, than the baby that you conceive."[19]

It is stated that Morelli knows how to make high level works also by using poor materials, if this is what the commission allows: his buildings have an intrinsic elegance they are infused in his style. The lesson that he gives to his fellows is made by considering carefully the final product that will be realized, no matter if it is a skyscraper or a simple drawer. The technology of the materials is the key for resolving the architectural problems, states Morelli. hat stems from the fact of following a prototype where there are not possible any corrections. The focus on the perfection of final work and not the economical profit, is the example that Morelli taught us to follow in the professional life. Let's magnify a little bit the vision on the materials in the section below.



Relation with materials

In this topic, the architect has found a breaking point of rationalist architecture in the use of the new materials introducing the concept of "disloyal materials" as he called them. In a brief he expresses his idea as following: "The architecture of the precedent years (referring to the years '30) was based in decorations of shapes and leaves; and was enriched by statues. Those decorations became dirty, obsolete with the passing of time which gave them a certain fashion. The modern architecture, is in fact based on the net surfaces, representing the ornament by their rhythm of the windows… Well, this type of architecture, refined by plasterwork is special, more researched and more solid from the previous one, did not hold up the comparison with time and did not bring good results…"[20]
Being faithful to his ideas, Morelli used to play with the materials mixing them up and evolving with the passing of time and depending on the project.

His choices of materials in the design of building façades, with the marble and the stone down, the plasterwork in the high parts and evolving with other variable solutions in the '50 keeping a vigilant sensibility: between clinker, artificial stone and brick, the enclosures in wood, eviting the use of standard productions and mass scale productions. The strong connection that he had also with the artisans made his choices responsible and feasible for the further process, that of the building. Affirming this way, the initial statements of T. Finzi() that his designs were conceived together with the building process.

Professional figure

In the end Morelli can be affirmed as a complete professional. His figure is rich of fantasy and at the same time has a great logical strictness. He can cut and redefine his own design theme, knowing how to impose the ratio of the design at every aspect: distributive, structural, plant, compositional.

[19] <<Lettera a Domenico Bagliani>> T. Finzi.
[20] <<Il tradimento dei materiali>> E. Garda.

Important is also the ability to govern the interrelations of different components and the building physics problems having the courage to make a choice and cut-off the unnecessary parts by synthesizing! It's well described by Bardelli that in this figure there are two spirits that live together: the one who likes to experiment, and the one who loves the freedom of formality. This kind of freedom can be valid for many arts, but for architecture it should be subjected to a strong self-control. The architect is omnipresent from his office to the table, to the site. He is a professional who works and meditates, discusses with the commission and with legislators, but in the end, he is the one who makes the choices based on the difficulty of producing, the time it takes, the process of using them in the site. Only in this way our professional can make the difference and try to experiment different techniques, mostly detailed and extremely interesting. I would like to conclude with a description from his associate Sergio J.Hutter :"Many times, I have assisted with profound admiration in the position he used to take when judging in the construction site. Knowing in detail the project he was sometimes in favor of the commission and other times in favor of the enterprise. In fact, the completeness of architect's personality is deduced by the arbitrary decisions that he takes in the construction site. So, if the cultural formation of the architect provides also an external vision of the design and embraces the cult of equity we can say that his design will be complete, not only in the materials use, but also in their implementation and programming during the building process.[21]"

[21] <<Corso Vittorio Emanuele 74. Uno studio democratico>> S.J. Hutter.

3. Energy draft of the skyscraper RAI in Cernaia avenue 33, Turin, ITALY.

Nowadays, the tall steel and glass skyscrapers that emerge from every corner of the world look alike, even though the cultures are different, the climate changes and the territory is diverse. They look more like cars than organisms which are shaped and belong to a precise location. The change of mechanistic view of the building machine should occur in order to leave space to more sustainable approaches. There is no more time for exploitation of resources, because we live in a planet that has limited boundaries. Since the first studies carried out from the MIT systems dynamics group[3], for the limits of growth in our planet, have proven to be realistic, an action is necessary to be taken.

The facility of the case study is abandoned due to high energetical costs and the inability to make proper maintenance, since the limitations of the legislative decree approved in 1992 regarding the health and safety of the workers made it impossible to interfere in the structure, because it had asbestos. The intervention is made considering this fact and different simulations are run in order to choose and quantify the proper design solution for minimizing the costs in the energy usage. The consume of energy in buildings is a principal aspect to be studied generally, since it corresponds to around 40 % of the total energy in USA and Europe according to the article[4] and with some interventions the buildings can save energy until a point that they can actually become active producers of energy. This is the case of ZEB buildings.

The highrise building was chosen as the most suitable part of the complex to make the energy study. This conclusion came due to the fact that it presented the higher surface area vertically built in a curtain wall. A study for determination of Heating and Cooling Loads occurred first, to determine the current state of the facility. The procedure is based on the UNI EN ISO codes (UNI 6946, UNI 10077, UNI10339, UNI 10349, UNI 14638, UNI 13947) which are mentioned in the calculus method that follows. The entity of Heating and Cooling Loads is necessary to determine the design of the Power plants, heating and refrigerating ones and determine also if the transmittances satisfy the current Decrees in Energetical matter. The same data of input that regards the materials is used to make the energy model in Revit , different levels of details were considered. The first study consisted in making the simulation only with masses and using similar parameters according to ASHRAE building regulations. The other model consisted in the actual building elements of the skyscraper. In the next chapter the design proposal has considered the data provided by these models to reduce in a clever way the energetical consumption. The cloud service GBS of Autodesk was used to complete the calculations.

Theoretical and methodological principles

The calculus of thermal loads in both regimes, winter and summer, is the fundamental step for the correct dimensions of the HVAC systems and the relative components, since the value determines the dimensions and characteristics of the piping for the heat generating fluids, boilers, refrigerators, air distribution channels. More generally, all the energy conversion systems as well as the air conditioning and its terminals. The definition of thermal load is the following:

"The flow of energy that is needed to be input or subtracted from a confined space to maintain the desired conditions inside (with particular attention to relative temperature and humidity)."[22]

[22] Perino. M. "*Chapter 14, Calculus of thermal loads*" 2008 Milano. P.1.

The study is made in order to determine the entity of the peak value of the thermal load, for two regimes. During the winter time, the temperature difference between indoor and outdoor environment is constant, while in the summer period it has 24 different values for each hour.

There is the possibility to extend the calculus and make the determination of the time profile of the thermal load needed to estimate the energy consumption of buildings. In this case study this part is quickly simulated with the Autodesk Energy Analysis program GBS and a detailed study is not made.

3.1. Determination of heating loads

Since the skyscraper is supplied by a unique heating system, the first hypothesis made for the calculus is to consider the tower as a unique thermal zone. Due to its regularity and modularity of the floors (1-16 are identical) and approximating that the first floor and the 17th are similar, the whole building is considered as one zone. The palace has a façade surface of 6500 m^2 approximately, that will be examined in detail.

Figure 46 Unique thermal zone hypothesis and the relative dispersions

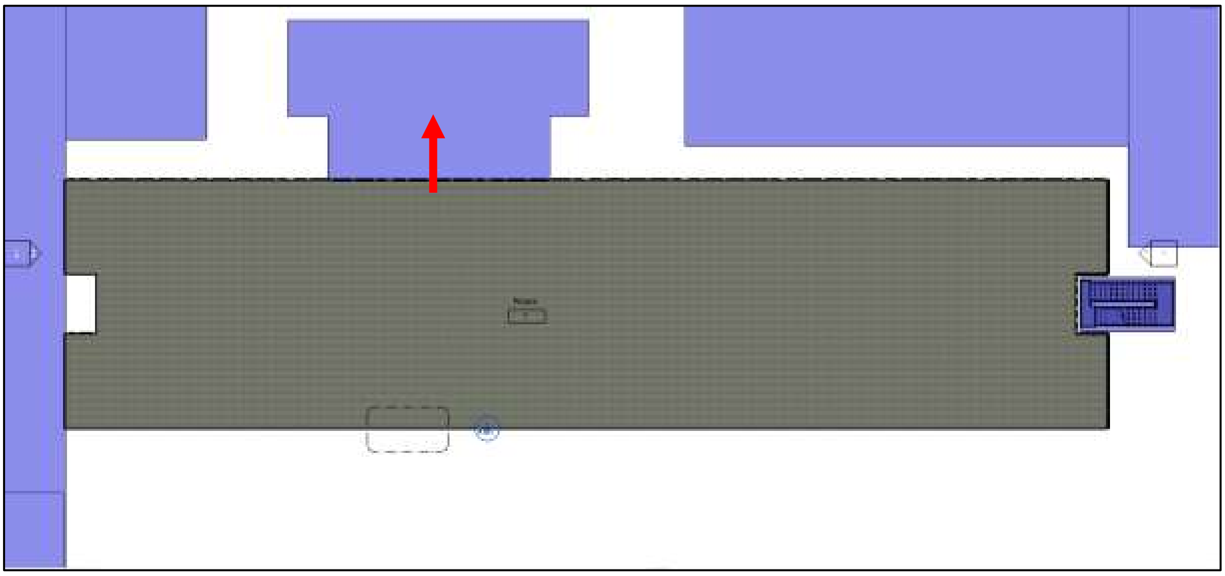


Figure 47 The dispersion towards the unheated zone of the scale

3.1.1. The input data

The data used for the project regards the climatic conditions of the site

- θ^*_e =-8°C Project external temperature for Turin

This value is given in table N.A.1 of the National Annex of the EN 12831 standard that can be further seen in the attachment A1_3.1.1.

- θ^*_i = 20°C Internal temperature of each room, obtained from table N.A.2 of the national annex of EN 12831 attachment A2_3.1.1.

3.1.2. Calculation of thermal transmittance

The envelope is constituted of a curtain wall that covers all the skyscraper and is the most dispersive part of the building. The opaque surface is composed of the two slabs that enclose the building. The ground floor slab and the roof slab.

Thermal transmittance of the opaque components

Calculation of the thermal transmittance of opaque surfaces was carried out according to the EN ISO 6946 and applying the sequent formula:

$$U = \frac{1}{R_{se} + \sum_{i=1}^{n} \frac{s_i}{\lambda_i} + \sum_{j=1}^{m} R_m + R_{si}}$$

where:

- R_{si}: internal limiting resistance [m^2K / W]
- R_{se}: external limiting resistance [m^2K / W]
- s: material thickness [m]
- R: thermal resistance of materials [m^2K / W]
- λ: thermal conductivity of materials [W / mK]

The values of R, are taken from table 1 of EN ISO 6946 according to the flow direction:

(Horizontal, Vertical ascending, Vertical descending) represented in the attachment A1_3.1.2.

The standard where these values were obtained from are: UNI 10355 standard that provides the values of thermal resistance of walls and floors, page 61, represented in the attachment A2_3.1.2.

Thermal transmittance of the transparent components

The calculation of the thermal transmittance of transparent surfaces was carried out with the following formula in accordance with 10777-1: 2007:

$$U = \frac{A_g U_g + A_f U_f + \psi_g i_g}{A_g + A_f}$$

where:

- A_g: area of the glazed surface (glass) [m^2];
- U_g: thermal transmittance of the glass [W / (m ^{2}K)] (supplied by the manufacturer);
- A_f: area of the frame (frame) [m ^{2}];
- U_f: thermal transmittance of the frame [W / (m ^{2}K)] (supplied by the manufacturer);
- l_g: glazed perimeter length [m];
- ψ_g: linear thermal transmittance of the thermal bridge due to the spacer between the glass [W / mK] (to be considered only in the case of multilayer glazing and supplied by the manufacturer, otherwise in the study case it was taken from the norm 10077);

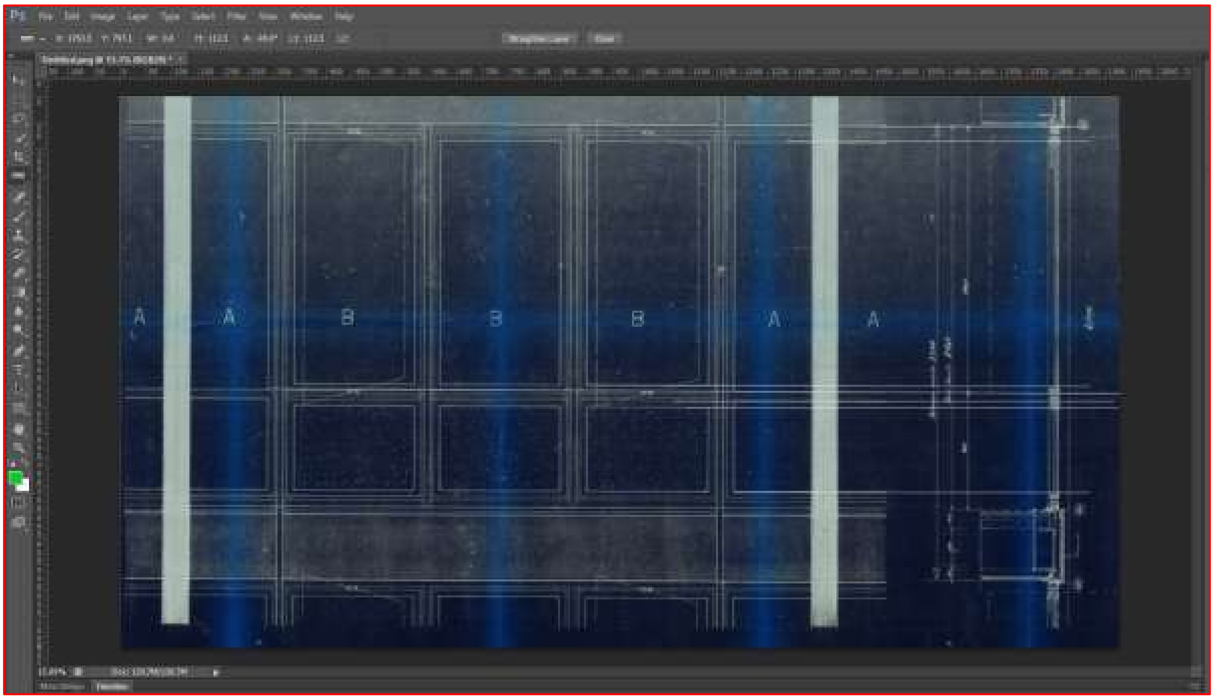


Figure 48 The façade representation with photoshop program where it can be seen a module.

The façade is the characterizing element of the building and it has a modular form of 5x3m that is repeated for the 18 floors.

The façade includes a series of main mullions, forming part of the supporting structure, of rectangular cross-section, framed by the same structure in correspondence of the planes, which remain outside the shuttering frame. The distance between the main uprights is 5 meters.

For the support of windows and doors, are foreseen secondary mullions in T-shaped steel sections which divide the span of 5 meters into three mirrors, respectively mt. 1.58 - 1.84 and 1.58.

These uprights are fixed by bolting or welding to the load-bearing structure and are previously treated with a process for protection against oxidation due to atmospheric agents; and are painted.

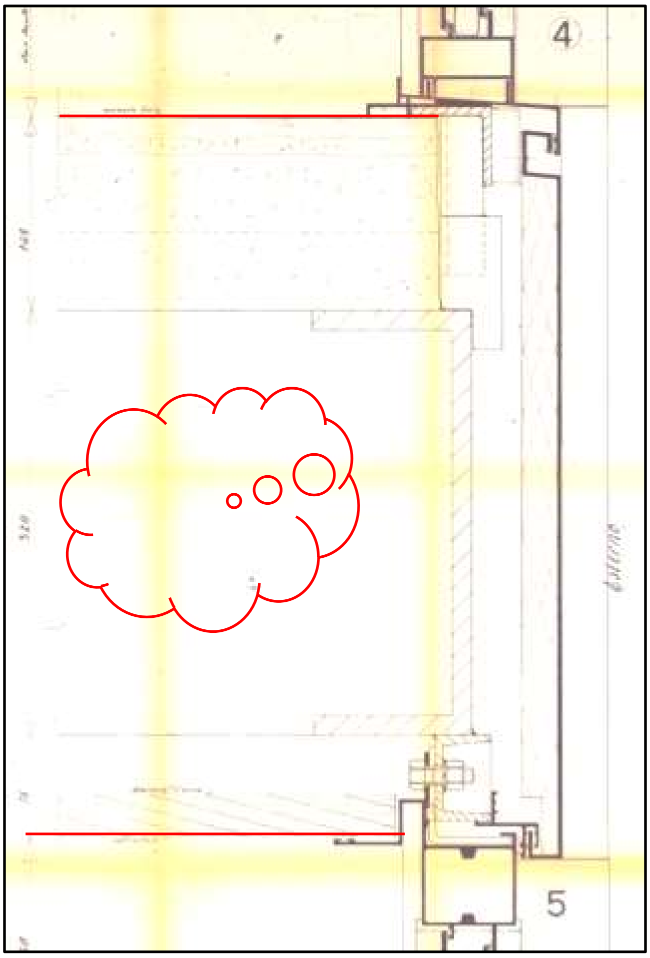


Figure 49 detail of the curtain wall window fixture, in the ceiling and floor in between there is air
SOURCE: Fondo Domenico Morelli

The window closes the gap between the floor slab on which it rests, the lower face of the ceiling and the two contiguous secondary uprights. Each horizontal is subdivided by the following from a string course.

Each frame consists of a framework in special profiles in light aluminum alloy forming two panels of m. 2.25, which are provided with glass Vetropan.

Each window has an opening flap, vertically bent and closable with a removable handle, as its opening is done only for exceptional needs or for cleaning.

For the pivotal play, on vertical axis, frictioned and thrust pin studs are used to support the weight of the bead.

The window includes the elements necessary for the application of the Venetian blind.

After getting the necessary information from the specific design represented in the attachment A3_3.1.2. it was proceeded with the calculus.

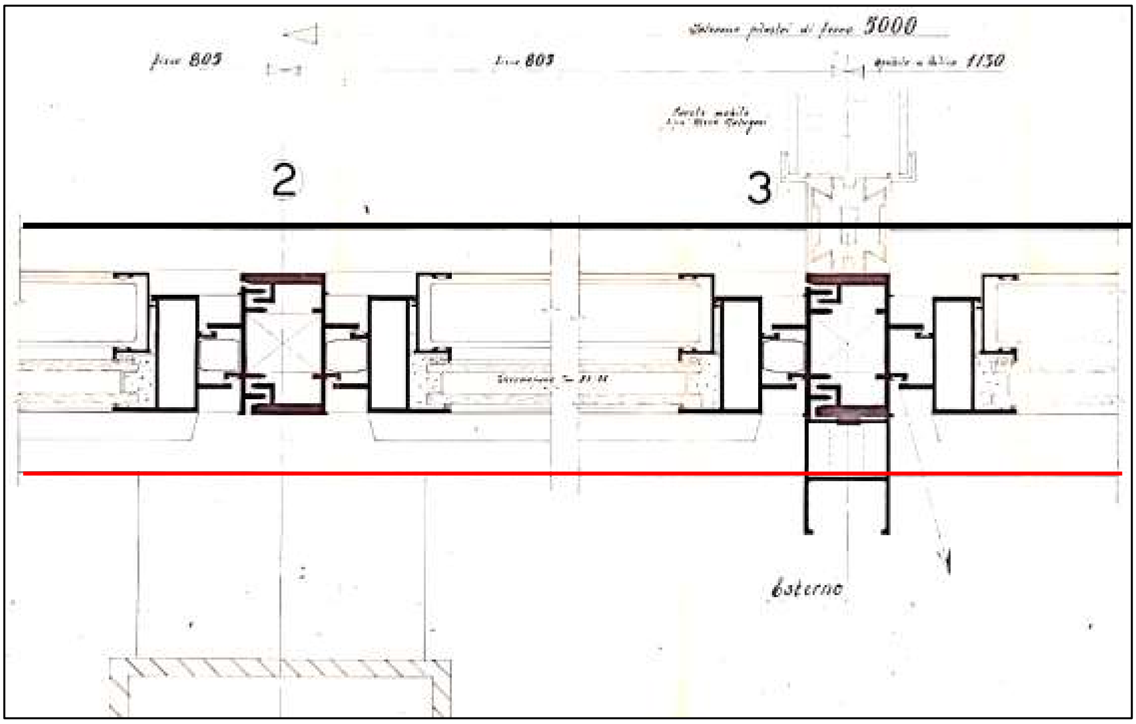


Figure 50 Details of the façade components external red internal black. SOURCE: Architecture Library POLITO

Calculus procedure

First, it was selected the typical window of the skyscraper. The separation and the calculation of the glazed area A_g and A_f successive step made. Then this number was multiplied with the factor of repetition of the window in the whole floor. Finally, this result was multiplied with the total number of floors to give the total surface of the façade in that particular exposition. The value of this calculation is represented in file C_3.1.2.

Figure 51 The original façade design
SOURCE: Fondo Morelli

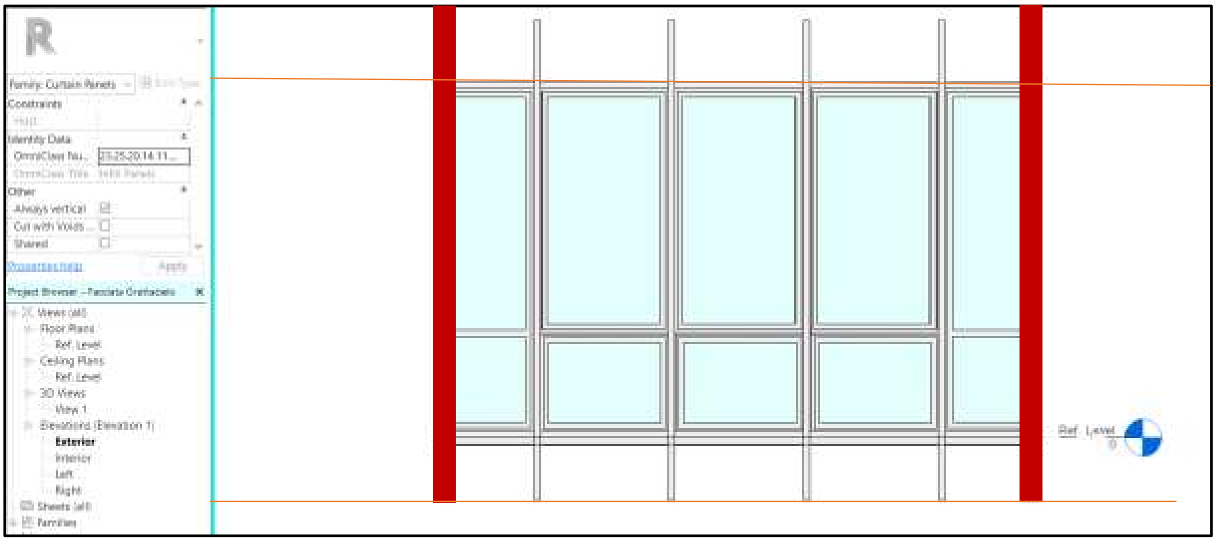


Figure 52 The reproduction of the façade in 3D in Revit 2017

The typical values for the thermal transmittance of the glass are found on the standard 10077:1-2007 in table C.2 and in the same standard can be found also the linear thermal transmittance represented both in the attachment A4_3.1.2. The frame values were taken from the same normative represented in the A5_3.1.2. The thermal bridges values were obtained from the Table A2 UNI EN ISO 14683 also represented in the attachment A5_3.1.2.

3.1.3. Calculation of Transmission heat flux

This flux is lost because of conductive heat transfer phenomena. More generally of the combination of convective / radiative exchange, that occur inside of the walls that divide the heated space from the outside environment or from other spaces at different temperatures. For the single heated room / heat zone, project losses can be calculated using the expression below:

$$-\phi_c = \left(H_{T,e} + H_{T,uh} + H_{T,ij} + H_{T,t}\right) \cdot (\tilde{\vartheta}_1 - \vartheta_e^*)$$

- $H_{T,e}$: loss coefficient for transmission between heated environment and external environment [W/K];
- $H_{T,uh}$: loss coefficient for transmission between heated and non-heated adjacent rooms [W/K];
- $H_{T,ij}$: [loss coefficient for transmission between heated environment and adjacent rooms heated to a temperature significantly different from the design temperature of the heated environment W/K], type not present in our project
- $H_{T,t}$: loss coefficient for transmission between heated environment and ground [W/K]], type not present in our project

Loss coefficients

Heated environment and external environment ($H_{T,e}$)

The loss coefficient for transmission between the heated environment and the external environment expressed in W / K is a function of the type and characteristics of all the elements of the building envelope also including its linear thermal bridges which separate the heated environment from the outside; It is calculated with the following formula:

$$H_{T,e} = \sum_{k=1}^{n} A_k \cdot U_k \cdot e_k + \sum_{l=1}^{m} \psi_l \cdot l_l \cdot e_l$$

- A_k: area of the surface that separates the heated environment from the external environment; the areas taken into consideration in our project are the external ones;
- U_k: thermal transmittance of the surface that separates the heated environment from the external environment;
- ψ_l: linear thermal transmittance of the linear thermal bridge;
- l_l: length of the thermal bridge;
- e_k, e_l: exposure factors: consider the influence of relative humidity, wind speed and the different air temperature on the heat exchange of the building envelope. These values were derived from the national annex to the UNI-EN 12831 standard. Attachment A1_3.1.3.

Table 5 The transmission loss coefficient towards the environment

$H_{T,e}$ TRANSMISSION LOSS COEFFICIENT TOWARDS THE ENVIRONMENT					
ORIENTATION	AREA [m^2]	AERAL TRANSMITTANCE [W/m^{2}k]	EXPOSITION e_k [-]	$\sum_{k=1}^{n} A_k * U_k * e_k$	
Nord_Est	765.47	4.45	1.2	4091.60	[W/K]
Nord_West	2704.56	4.45	1.15	13854.14	[W/K]
Sud_Est	2194.25	4.45	1.1	10751.36	[W/K]
Sud_West	765.47	4.45	1.05	3580.15	[W/K]
			TOT	32277.25	[W/K]

Table 6 The linear transmission coefficient towards the environment due to the linear thermal bridges

TRANSMISSION LOSS COEFFICIENT TOWARDS THE ENVIRONMENT LINEAR					
ORIENTATION	LENGTH [m]	LINEAR THERMAL TRANSMITTANCE [W/mK]	EXPOSITION e_k [-]	$\sum_{l=1}^{m} \psi_l \cdot l_l \cdot e_l$	
Nord_Est	1054.00	1.00	1.2	1264.80	[W/K]
Nord_West	2431.00	1.00	1.15	2795.65	[W/K]
Sud_Est	1975.40	1.00	1.1	2172.94	[W/K]
Sud_West	1054.00	1.00	1.05	1106.70	[W/K]
			TOT	7340.09	[W/K]

Heated environment and unheated environment ($H_{T,iuh}$)

The loss coefficient for transmission between heated and non-heated adjacent areas expressed in W / K is a function of the type and characteristics of all the elements of the building envelope and of the thermal bridges that delimit the thermal zone under examination and the surrounding unheated, like the stairwell and the basement. Calculated with the following formula:

$$H_{T,iuh} = \left(\sum_{k=1}^{n} A_k \cdot U_k + \sum_{l=1}^{m} \psi_l \cdot l_l\right) \cdot b_u$$

where:

- b_u: is the temperature reduction factor, which considers the fact that the temperature difference between the surfaces separating the heated and unheated rooms is different from the difference in temperature between the heated and the external environment.

The value of the coefficient is always calculated through the national annex. In the project, the stairwell has three opening to the outside. The value of the coefficient has been obtained from the table provided in the annex of the UNI - EN 12831: Attachment A1_3.1.3.

In the end of the calculations the heat flow lost for transmission is calculated and represented in the C_3.1.3. attachment.

Table 7 Transmission loss coefficient towards unheated space

TRANSMISSION LOSS COEFFICIENT TOWARDS UNHEATED ENVIRONMENT					
ORIENTATION	AREA [m^2]	TRANSMITTANCE [W/m^{2}k]	REDUCTION b_u [-]	$\sum_{k=1}^{n} A_k * U_k * b_u$	
Sud_Est_CS	510.31	5.80	0.8	2367.85	[W/K]

3.1.4. Calculation of intermittence heat flux.

Due to the low inertia of the building the calculation was made considering the low mass input of the table given in the normative 12831.

$$\phi_{RH} = f_{RH} \cdot A$$

where:

- A: surface area of the heated space;

- f_{RH}: correction factor.

f_{RH} is tabulated according to the intended use of the building, the time interval in which heating is required, the assumed temperature drop in indoor air during shutdown and thermal inertia, expressed in terms of mass. In the project a shooting time of maximum 1h and a temperature drop of 4 ° C was chosen.

These values are found in the national annex of the UNI-EN 12831 standard, attachment A1_3.1.4.

Table 8 Intermittence flux calculation

INTERMITTANCE FLUX	As	f_{rh}	n	ΔΘ	φ_{int}
	[m²]	[W/m²]	[h]	[K]	[W]
Values	10200	36	1	4	367200
				TOTAL ϕ_a	367200.00
				ϕ_c/sup	36.00

3.1.5. Calculation ventilation heat flux.

This flux was calculated using the values given from the UNI 10339 standard attached in A1_3.1.5 in base of intended use there are given the numbers of emission or extraction rates. This number is multiplied with the number of people present in the offices.

$$Q = n_s \cdot A \cdot Q_{op}$$

- $n_{s:}$ crowding index expected for m² according to prospect VII UNI 10339
- $A_{:}$ area of the considered environment;
- $Q_{op:}$ external air flow per person according to prospect III UNI 10339.
  In terms of air changes times n (ACH: Air Change per Hour):

$$n = \frac{Q}{V}$$

The external air flow (Q) to be introduced into the environment is calculated according to the following formula:

$$Q = A \cdot Q_{os}$$

- A: useful area of the considered environment;
- Q_{os}: air flow to be extracted according to prospect III UNI 10339

The values are specified in the attachment A1_3.1.5. which gives the power of the plant as the total sum of the heating loads.

Table 9 The final calculus of the ventilation flux

VENTILATION FLUX	H	ϑ^*_i	ϑ^*_e	φ_a
	[W/K]	[°C]	[°C]	[W]
$H_{v,e}$	18122.5	20	-8	507431.23
			TOTAL ϕ_a	507431.23
			ϕ_c/sup	45.23

3.1.6. The heating load of the existing situation.

Finally, the total sum of the three fluxes determines the design heating loads of the system. This value is divided with the total floor area of the facility, to make its value comparable to other values defined by norms. Table 10 The total flux of the existing situation in the winter season

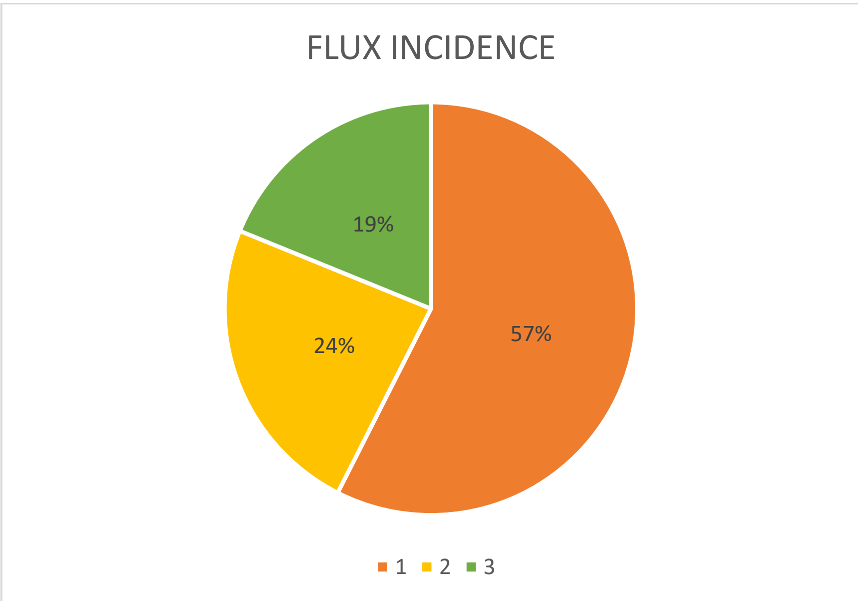
The value is high due to the low quality of the transparent components in the envelope, since they are outdated and the ability to maintain the heat is low.

Table 11 The pie chart and relative tables of the existing situation in the winter season

TRANSMISSION FLUX	H [W/K]	ϑ^*_i [°C]	ϑ^*_e [°C]	ϕ_c [W]
	39617.34	20.00	-8.00	1109285.58
	2367.85	20.00	-8.00	66299.84
	1320.00	20.00	-8.00	36960.00
	671.19	20.00	-8.00	18793.22
			TOTAL ϕc	1231338.64

VENTILATION FLUX	H	ϑ^*_i	ϑ^*_e	ϕ_a
	[W/K]	[°C]	[°C]	[W]
	18122.5	20.0	-8.0	507431.2
			TOTAL ϕa	507431.232

INTERMITTANCE FLUX	As	f_{rh}	ΔΘ n	ϕ_{int}
	[m²]	[W/m²]	[K] [h]	[W]
	11220.0	36.0	1.0	403920.0
			TOTAL ϕ_a	403920



3.1.7. The design heating load of the system and effectiveness of the intervention results.

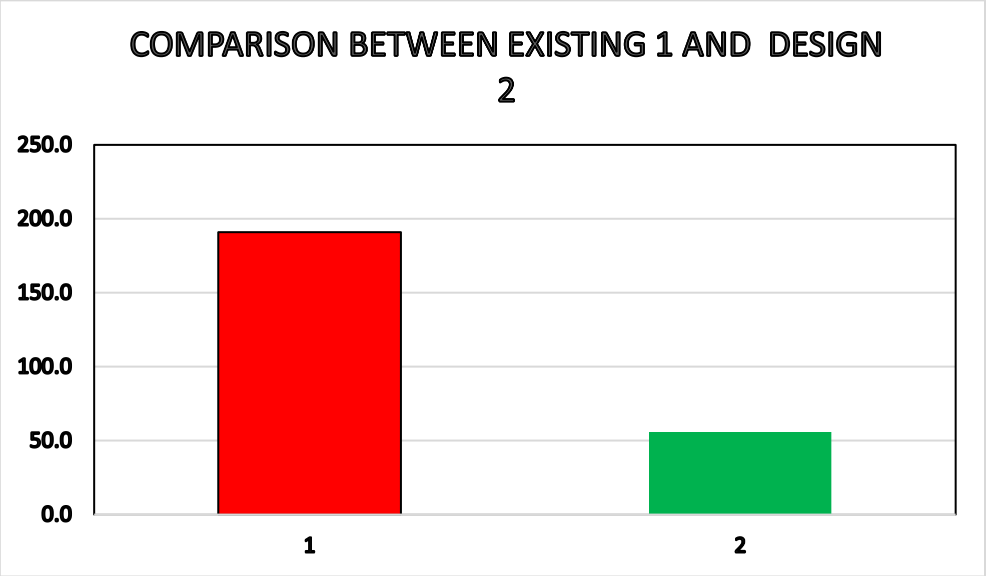
The results obtained from the intervention are compared with the existing situation calculated in the 3.1.6. paragraph, in order to determine its efficacity.

Table 12 Total flux during the winter time after the design intervention

	φ_c	φ_a	φ_{int}	Φ_{TOT}
	[W]	[W]	[W]	[W]
TOTAL FLUX	154925.2	46143.8	367200	568269.0002
			Φ_{TOT} /mq	**55.7**

The final value of the calculus shows a reduction of 134 W/m^{2,} in other terms 70% less heating loads for the winter period. That is translated in less costs for the energy. The precise value of this economical return is object of a more detailed economic analysis, but the common sense suggests that also a reduction of the costs at minimally around 50% should occur. The components which are used in the design are highly efficient and respect the minimum values imposed by the standard[23] in Italy.

Table 13 The chart shows the reduction of thermal load in the winter time, comparing the existing situation with the design



[23] D.M. 26/06/2015: *Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici.* A cura di Vincenzo Corrado.

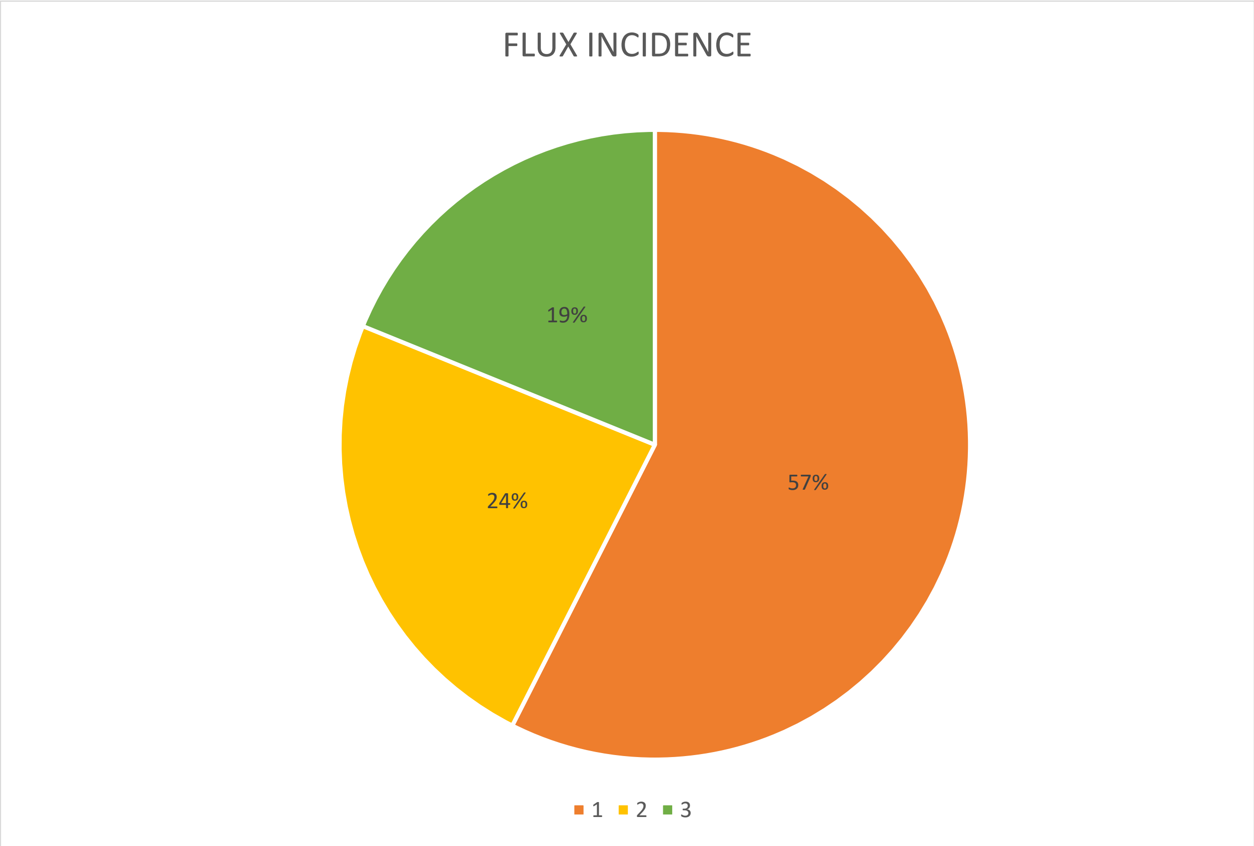
Table 14 Design heat fluxes

	H [W/K]	ϑ^*_i [°C]	ϑ^*_e [°C]	ϕ_c [W]
TRANSMISSION FLUX	3498.69	20.00	-8.00	97963.40
	1717.55	20.00	-8.00	48091.38
	198.00	20.00	-8.00	5544.00
	118.80	20.00	-8.00	3326.40
			TOTAL ϕc	154925.1794

	H [W/K]	ϑ^*_i [°C]	ϑ^*_e [°C]	ϕ_a [W]
VENTILATION FLUX	1648.0	20.0	-8.0	46143.8
			TOTAL ϕa	46143.8

	As [m^2]	f_{rh} [W/m^2]	ΔΘ n [K] [h]	ϕ_{int} [W]
INTERMITTANCE FLUX	10200	36	1	367200
			TOTAL ϕ_a	367200

Table 15 The percentages of different fluxes in the winter season after the new design



3.2. Determination of cooling loads

3.2.1. Climatic data

The data is obtained from the UNI standard 10349 and the calculations are made following the guidelines of the manual[24] of determination of heating and cooling loads. Its principal finality consists on the determination of the irradiance and the solar temperature of the outdoor environment. In this case it has 24 variable values, since the temperature fluctuations are notable comparing the night time and daytime. The calculus hypothesis is based in a specific day that represents statistically, the most suitable usage of the cooling system.

The temperature is calculated following the expression:

$$\Theta_{max} = \Theta_{max,r} - (z - z_r) \cdot \delta$$

where:

- θ(t) is the maximal temperature of the external air during the day
- F(t) is the distribution factor of the temperature
- Δ θ($_{max}$) is the daily excursion of the external air.

These values can be found in the standard 10349 in prospect V and XVI respectively, represented in the attachment A1_3.2.1.

Irradiance

The maximal irradiance that propagates in the surface of a building component, is calculated as follows:

$$I_T(\varphi) = I_T(\varphi_{r1}) + \frac{I_T(\varphi_{r2}) - I_T(\varphi_{r1})}{\varphi_{r2} - \varphi_{r1}} (\varphi - \varphi_{r1})$$

dove:

- I_T *(φ)* is the maximal radiation relative to the surface located in *φ* latitude, oriented in a specific direction.
- *φ* is the latitude of the building location:
- *φ* $(_{r\,1})$ is the latitude immediately after the one of location;
- I_T (φ_{r1}) is the maximal solar radiation relative to the orientation of the surface under examination
- *φ* $_{(r2)}$ is the latitude immediately before the one of location;
- I_T (φ_{r2}) is the maximal solar radiation relative to the orientation of the surface under examination

The values are represented in the attachment A1_3.2.1. taken from page 29 of UNI 10349 and the calculation results in the C_3.2.1. attachment.

[24] Perino *Capitolo 14 Calcolo dei carichi termici* 2008 Milano p. 94.

Solar temperature

The values of this parameter, which represents a synthetic characterization of the climatic conditions in the external environment are calculated following the standard 10349 with the following formula:

$$\theta_{sa} = \theta_e + \frac{\alpha \cdot I}{h_e}$$

Where:

- $\boldsymbol{\theta_e}$ is the external temperature;
- **I** is the total solar radiation (direct and diffused) incident on the external surface of the components of the envelope;
- $\boldsymbol{\alpha}$ absorbing coefficient of the external surface of the components of the envelope;
- $\boldsymbol{\varepsilon}$ hemispherical integrate emissivity, in the infrared of the external surface of the components of the envelope;
- $\mathbf{h_e}$ liminar external coefficient;

The values of this calculations are represented in the attachment C_3.2.1.

3.2.2. Endogenous heat gains

The heat gains generated in the internal environment are calculated following a prescriptive approach, given by the international normative ASHRAE FUNDAMENTALS. The three heat gain generators that are considered are: People, illumination and electrical machines present in the office.

People

The quote of heat gains produced by people depends on the activity. In an office building, people do easy physical activities. The value, together with the separation in radiative or convective quote is obtained from the table of ASHRAE, represented in the attachment A1_3.2.2.

Successively, is calculated the number of people occupying the facility using the standard 10339, as it was done in the calculation of the winter heat loads in the paragraph 3.1.5

These calculations are represented in the C_3.2.2.

Illumination

To calculate the existing heat gains deriving from illumination, a site inspection was made in the beginning to determine the typology of the appliance and the total number in each floor. Then it was calculated as represented in the C_3.2.2.

Electrical machines

The heat gain of the electrical equipment is calculated in base of the values suggested from the ASHRAE book of fundamentals. Table 3 of the attachment A1_3.2.2. and the calculus is represented in the C_3.2.2.

3.2.3. Cooling loads quote of transmission from transparent components

The procedure for calculating the flux is a simplified one based on the transfer coefficients

$$\Phi_{cd}(\tau) = f_c \cdot \sum_{k1=1}^{d,op} \left[U^{k1} \cdot A^{k1} \cdot \sum_{z=1}^{24} b_z \cdot \left(\theta_{sa,j}^{k1} - \tilde{\theta}_i \right) \right] + \boxed{f_c \cdot \sum_{k2=1}^{d,trasp} \left[U^{k2} \cdot A^{k2} \cdot \sum_{z=1}^{24} b_z \cdot \left(\theta_{e,j}^{*} - \tilde{\theta}_i \right) \right]} \quad (14.99)$$

Since the envelope consists of transparent components, the formula used for the calculations considers only the second part of the formula 14.99 taken from the technical manual[25] in chapter of calculation of the heating and cooling loads.: A fundamental element of this formula is the calculation of the b_z.

Calculus of coefficients of transfer b_z

These coefficients, 24 in total are calculated considering the frontal mass characteristics and that of the internal environment. In this study case the envelope consists of a façade and internal divisors that have a low mass. So, the thermophysical parameters for the calculation of b_z are assumed to have a value of 0 respectively. The values are taken from tables in the aforementioned manual and the procedure is explained in the section below:

Superficial mass determination and other parameters needed for determination of cooling loads with the simplified method of heat transfer coefficients (Perino, 2008)

$$m_b = \frac{m}{A} = \sum_{i=1}^{n} \rho_i \cdot s_i$$

m_b is the frontal mass necessary to determine the effective primary and secondary mass needed to characterize the environment mass, for determining the heat transfer coefficients. In this case study it is equal to 0 as stated before due to the presence of only the transparent components in the envelope. This way the values for the b_z are taken from the first row of the table 14.33 due to the low mass of the internal environment. Attachment A1_3.2.3.

3.2.4. Cooling loads quote of endogenous and radiative solar heat gains transmission.

This method[26] does not consider the source of the radiative heat gains. It only considers the total of the radiative heat gains and applies a coefficient u_z. The procedure for determining these 24 values is similar with the one of the b_z.

$$\Phi_{cr}(\tau) = f_r \cdot \sum_{z=1}^{24} u_z \cdot \left[\left(\Phi_e^{hg} \right)_{rad} + \Phi_{trasp,dir}^{hg} + \Phi_{trasp,diff}^{hg} \right]_j$$

Calculus of coefficients of transfer u_z necessary for the determination of the cooling loads of radiative sources of endogenous and exogenous sources is made with the help of the Tab 14.34 taken from the manual attached in the sheet A1_3.2.4.

[25] Perino *Capitolo 14 Calcolo dei carichi termici* 2008 Milano p. 108.
[26] Formula 14.103 taken from the same manual of calculus.

3.2.5. Cooling load quote of ventilation

The heat flux exchanged due to the ventilation, is made by convection so all the heat gains are considered as cooling loads instantly.

$$\Phi_a(t) = \Phi_a^{hg}(t)$$

The quantification of this contribute is made by the following formula:

$$\Phi_a^{hg} = \Phi_a(t) = \sum_j q_j(t) \cdot \rho \cdot c_p \cdot \left[\theta_{entrante,j}(t) - \tilde{\theta}_i\right]$$

With the terms analogical as the ones of paragraph 3.1.5. with the only difference that the temperature has 24 values, varying each hour of the day. The values are able to be viewed in the attachment C_3.2.5.

3.2.6. The cooling load of the existing system

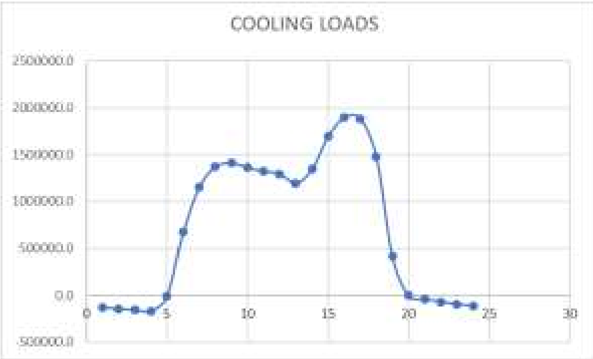
The final calculus consists in the determination of the maximum value of all the contributions. It is calculated with the formula below:

$$\tilde{\Phi}_{p,ed} = Max\left[\sum_{r=1}^{n} \Phi_{p}^{r}(\tau)\right]$$

- $\Phi_{r,p(t)}$ sum of cooling loads for each hour.

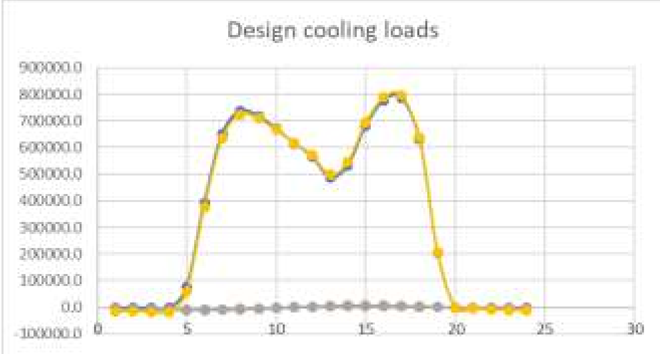
The value is given in the attachment C_3.2.6 and it is compared to the typical values given in the technical note of BSRIA attached as A1_3.1.6.

τ	Φcr(t)	Φv(t)	Φcd(t)	Φ(t)
1	0.0	-82820.0	-45647.4	-128467.4
2	0.0	-92787.4	-51138.4	-143925.8
3	0.0	-100761.3	-55530.6	-156291.9
4	0.0	-106741.8	-58824.0	-165565.8
5	158924.1	-108735.3	-59919.8	-9731.0
6	835032.1	-104748.3	-57719.2	672564.6
7	1301421.0	-94780.9	-52222.2	1154417.9
8	1489002.8	-76839.6	-42329.9	1369833.3
9	1488200.7	-50924.3	-28042.5	1409233.9
10	1394485.4	-21022.2	-11557.4	1361905.8
11	1301512.1	12867.0	7125.3	1321504.4
12	1229154.4	44762.7	21554.5	1295471.6
13	1093139.0	68684.4	35531.8	1197355.2
14	1216893.9	84632.3	45113.9	1346640.1
15	1556128.3	90612.7	49399.2	1696140.2
16	1765458.4	84632.3	47288.8	1897379.5
17	1775697.7	70677.9	40388.8	1886764.4
18	1401206.2	48749.6	29093.6	1479049.4
19	373781.6	22834.4	15206.5	411822.5
20	0.0	-3080.8	925.0	-2155.8
21	0.0	-25009.1	-11553.2	-36562.3
22	0.0	-44943.9	-22735.4	-67679.3
23	0.0	-60891.7	-31917.2	-92808.9
24	0.0	-72852.6	-38901.3	-111753.962
			MAX	1897379.5
			Φ(t)/sup	169.1



3.2.7. The design cooling load of the system and effectiveness of the intervention results.

τ	Φcr(t)	Φv(t)	Φcd(t)	Φ(t)
1	0.0	-5797.4	-7437.8	-13235.2
2	0.0	-6495.1	-8330.3	-14825.4
3	0.0	-7053.3	-9043.7	-16096.9
4	0.0	-7471.9	-9578.0	-17049.9
5	75135.9	-7611.5	-9754.0	57770.3
6	394166.3	-7332.4	-9392.9	377441.1
7	651202.6	-6634.7	-8494.4	636073.6
8	737264.4	-5378.8	-6879.5	725006.1
9	717712.2	-3564.7	-4548.2	709599.3
10	669630.3	-1471.6	-1858.7	666300.0
11	615426.1	900.7	1189.0	617515.8
12	565401.5	3133.4	3560.2	572095.0
13	487693.1	4807.9	5836.7	498337.8
14	532203.7	5924.3	7396.9	545524.9
15	680285.3	6342.9	8092.6	694720.8
16	775174.2	5924.3	7744.8	788843.3
17	785994.8	4947.5	6618.5	797560.7
18	630200.5	3412.5	4775.8	638388.8
19	204215.2	1598.4	2512.6	208326.3
20	0.0	-215.7	187.4	-28.3
21	0.0	-1750.6	-1841.9	-3592.6
22	0.0	-3146.1	-3661.0	-6807.1
23	0.0	-4262.4	-5153.0	-9415.4
24	0.0	-5099.7	-6286.7	-11386.41971
			MAX	797560.7
			Φ(t)/sup	78.2



The data shows a reduction of the value. To 78 W/m^2 which enters in the range of the norm defined by BSRIA. The savings are notable due to the intervention. The peak value has shifted to an hour later from 16:00 to 17:00.

3.3. Quick Energy simulation using the Autodesk GBS.

3.3.1. What is GBS ?

Acording to BEST (Building Energy Software Tools) :"Green Building Studio® (GBS) is Autodesk's core whole building energy simulation engine, and powers the energy analysis for Autodesk Insight 360, Autodesk Revit, and Autodesk FormIt 360. Green Building Studio is a flexible cloud-based service that allows you to run building performance simulations to optimize energy efficiency and to work toward carbon neutrality in the early conceptual phase of the design process. GBS will help extend your ability to design high performance buildings at a fraction of the time and cost of conventional methods".

Revit 2017 version is used as modelling program in this case study, since it supports energy analysis for both conceptual masses and detailed architectural components. Both tools make use of automated thermal zoning for conceptual masses, which closely follows ASHRAE codes.

Green Building Studio uses the DOE-2.2 simulation engine to calculate energy performance and also creates geometrically accurate input files for EnergyPlus. Key to the integrated interoperability exhibited is the gbXML schema, an open XML schema of the International Alliance of Interoperability's aecXML Group27.

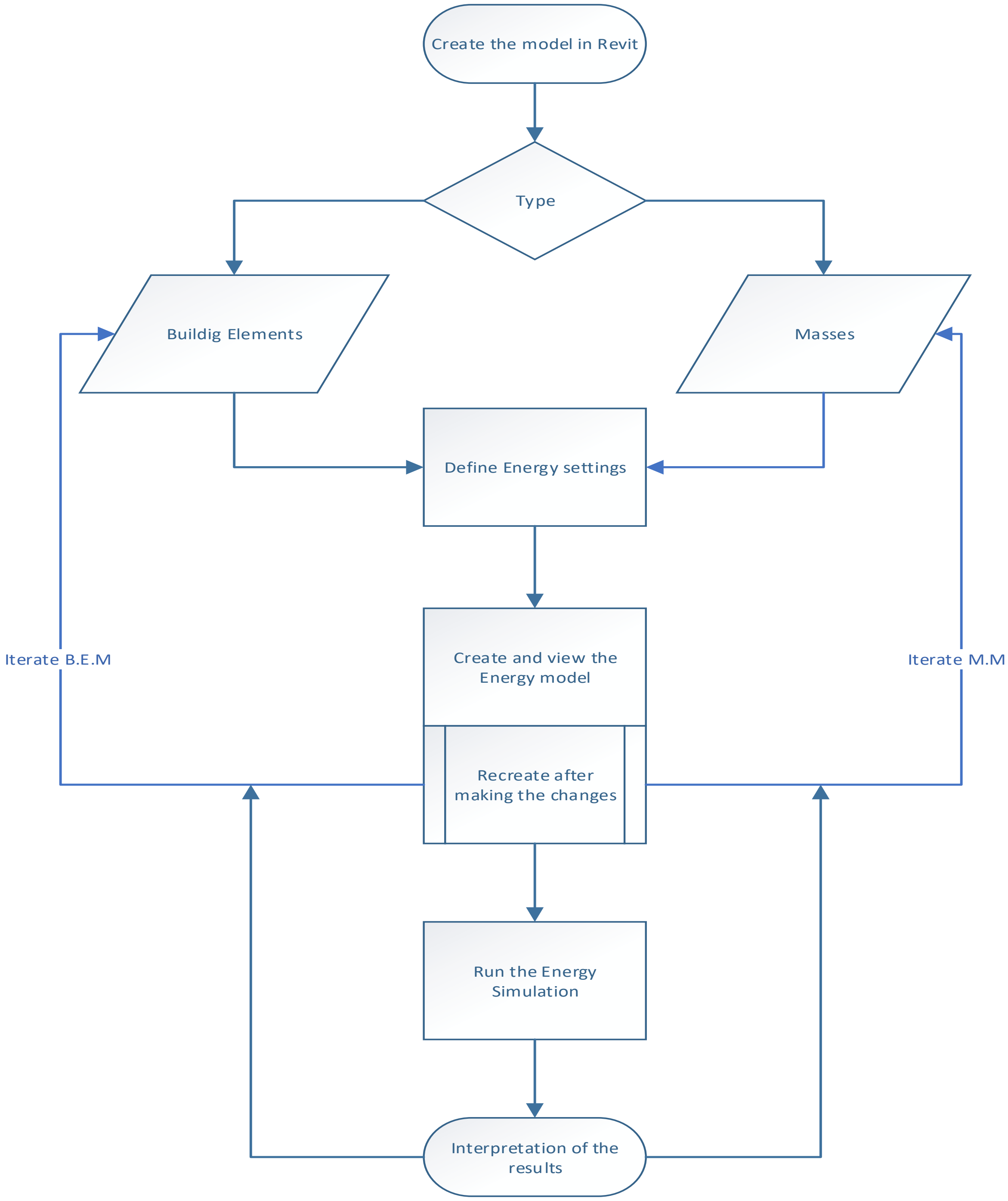
3.3.2. Results

According to the official page of Autodesk [5] : "The data in the chart comes from 37 separate energy simulation runs that are run simultaneously in the cloud. Each simulation varies a combination of 9 building features, including components like roof and wall insulation, glazing properties, lighting controls, and infiltration. These simulations are meant to test extreme values seen in new and existing buildings and help design teams get a high-level understanding of how sensitive the building's energy performance is to each parameter"28

[27] Information taken from the site
https://www.buildingenergysoftwaretools.com/software/autodesk-green-building-studio
[28] Information taken from the site
http://help.autodesk.com/view/BUILDING_PERFORMANCE_ANALYSIS/ENU/?guid=GUID-3FE7B133-18A3-4EA0-A726-B778432E2F6D 21/09/18

3.4. Workflow of energy analysis in Revit

The workflow that is followed during the creation of the model is represented in the scheme below and the description of this process is illustrated with program interface in next paragraphs.



3.4.1. Mass Model Building

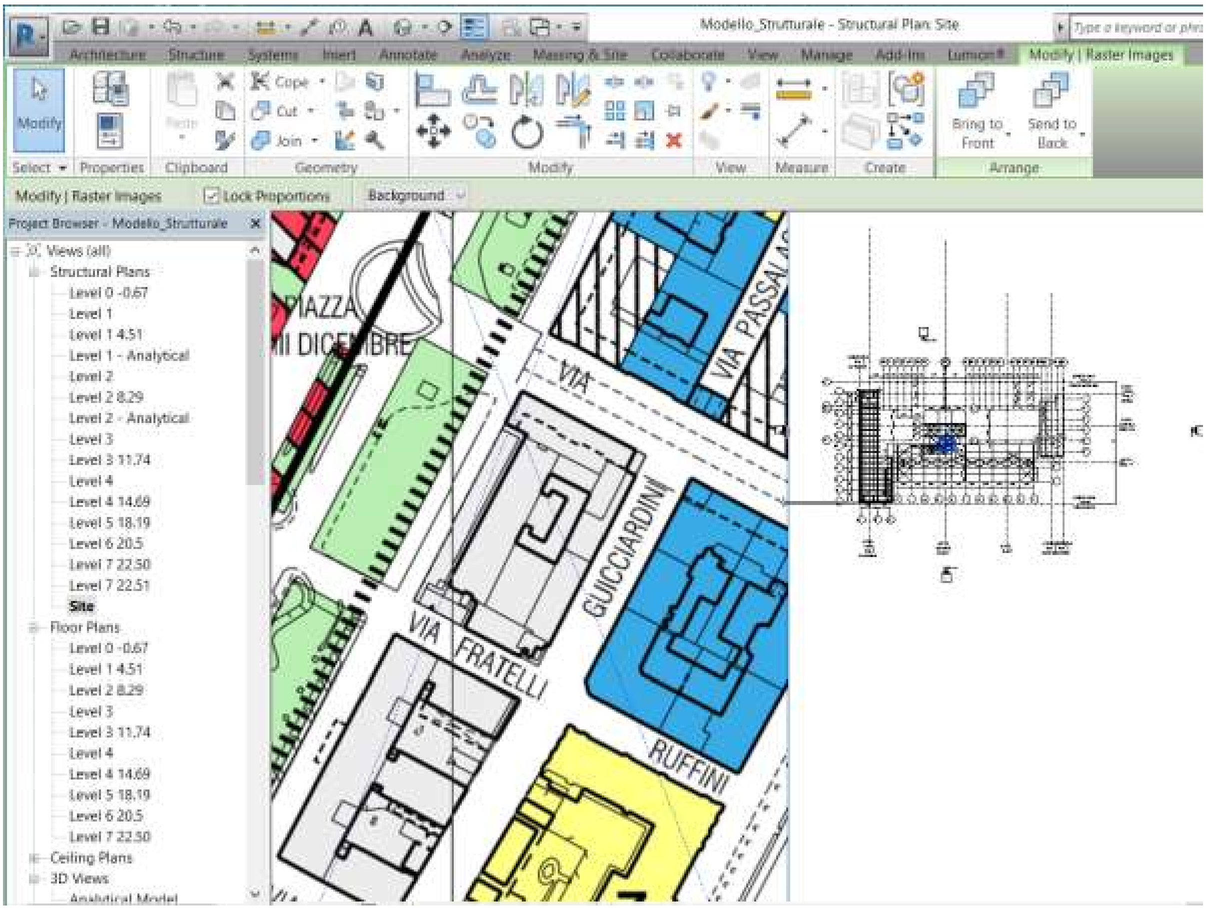


Figure 53 Overview of the program environment of the model
Source: Author

Before starting with the energy analysis, the context around the interested building was created. This permits the program to evaluate the position of the shadows during the different times of the day. The exact dimensions were extracted by an image file of the General Regulatory Plan of Turin city, updated in 09/2017.

After importing the image in the modelling program, some changes in scale and orientation were made to make it fit with the existing skyscraper model. Successively, the context in masses was created and the model fulfilled the requisites for performing an energetical analysis. The succeeding images represent the sequence of work made for the model creation.

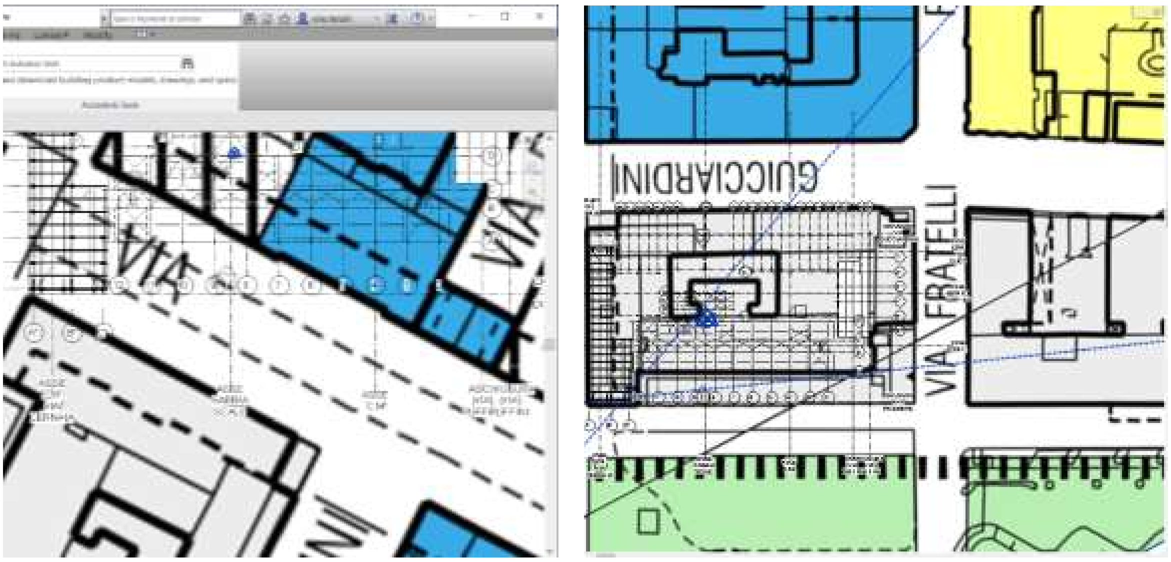


Figure 54 (Left) Positioning of the Model correctly and (Right) its rotation
SOURCE: Author

This phase is very important since it determines the orientation of the object because the analysis that follow consider the sun path according to this setup.

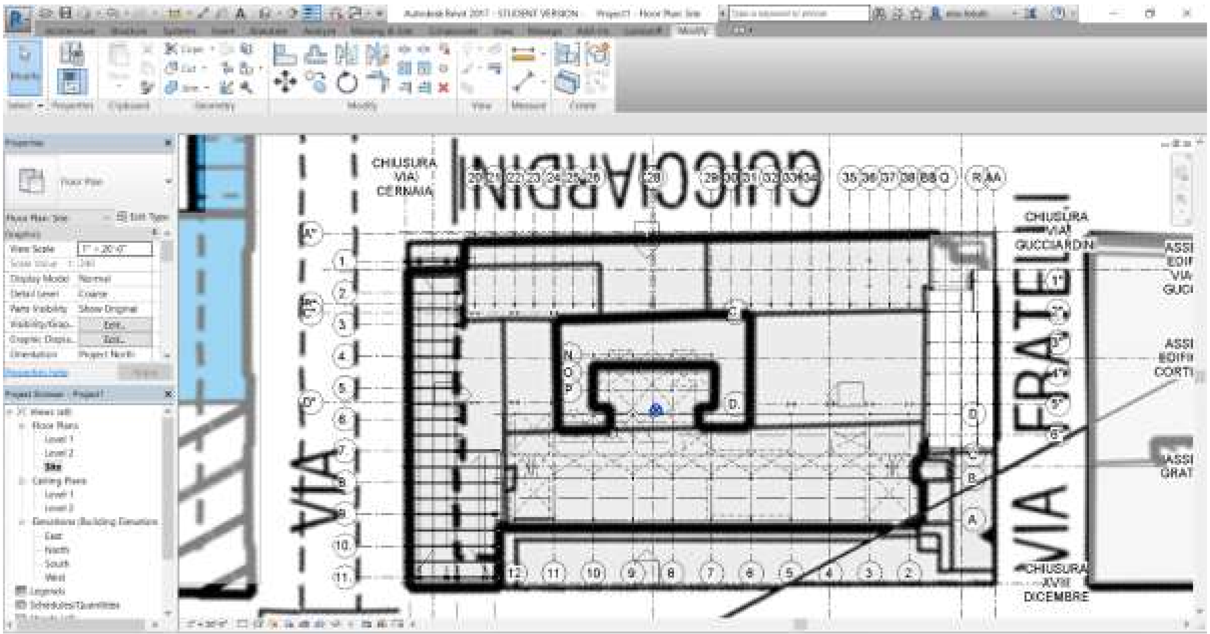


Figure 55 Final check for making sure that the model fitted almost perfectly to the existing image of Regulatory plan

The masses created, had two distinct functions. The skyscraper mass, being the one where the analysis would take part, consisted in a floor mass and a top mass that indicated its roof platform. The roof

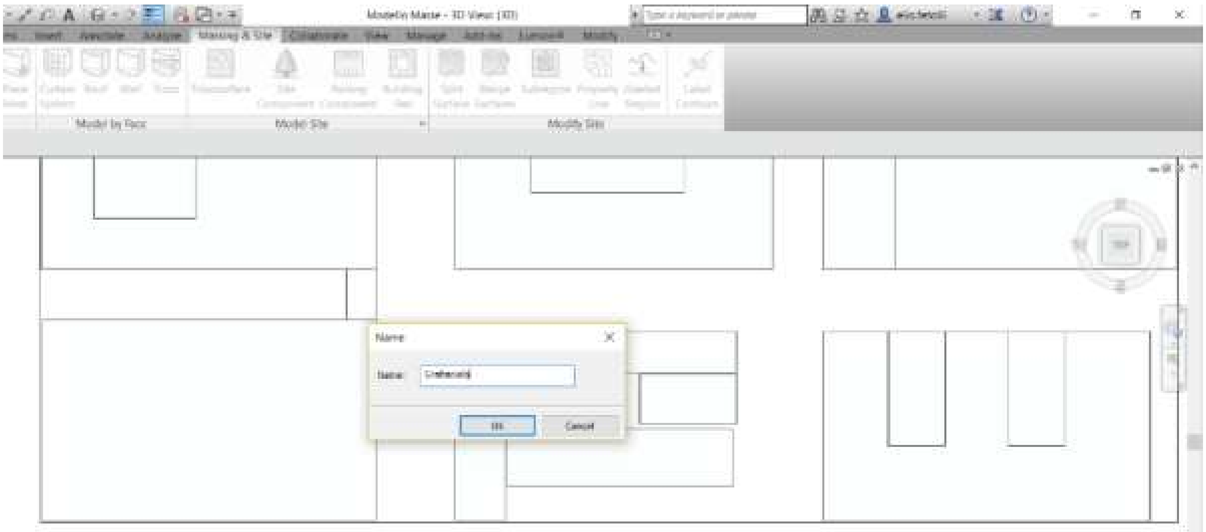


Figure 56 Creation of masses
SOURCE: author

was created as a single separate mass since it had only the function of calculating the shadow to the tower. The context around the building that was created, has only the purpose of determining the incidence of shadows in the skyscraper, so they were created as simple masses. In the end to complete the modelling of the mass model, a topographic surface that represents the park in front of the building at piazza XVIII Dicembre was added, together with the trees that would provide the necessary shading needed for the correct simulation. the figure below rappresents the site after the modelling of masses. Next step consists on the creation of the input data for the energetical analysis. Below an overview of the context is represented together with the sun path.

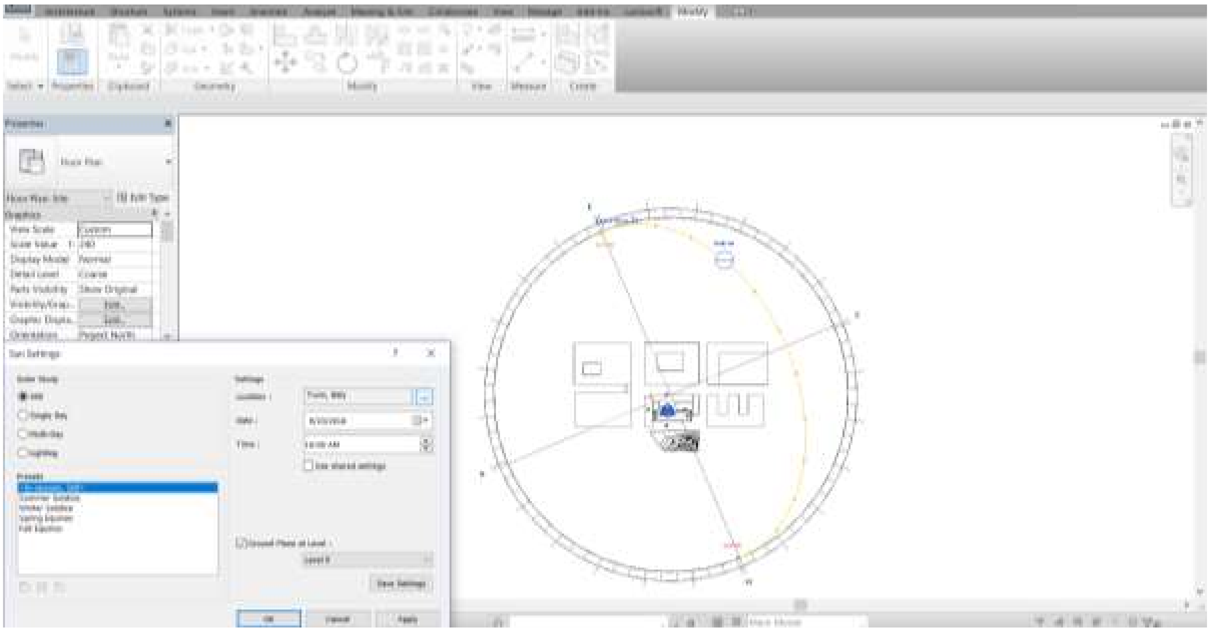


Figure 57 View of the sun path in the site of the mass model
SOURCE: author

Definition of energy settings

After the creation of the masses and the context the next step consisted in formation of the energy model, so inside the analyze tab, energy settings, the necessary information was filled as represented below in the first figure. All the input parameters are described in the following pages summarizing the information found in the Autodesk website[6].

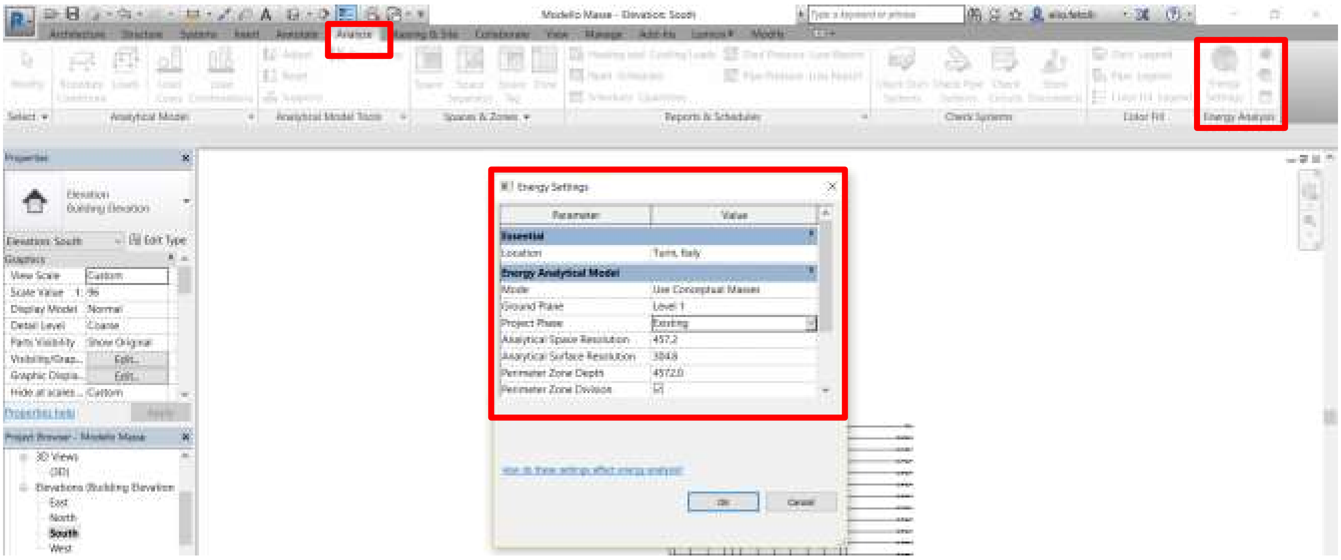


Figure 58 The input parameters of the model
SOURCE: author

Input description

This brief description is adapted from the website of Autodesk abovementioned.

In the option **Ground Plane** program asks for the level below which the energy model surface is assumed to be in contact with the ground for heat transfer. In our case it is the Underground level -2. The **Project Phase** considers the construction period**.** All building elements and/or conceptual masses assigned to the specified phase or an earlier building phase are included in the energy analysis. Elements and masses assigned to a later building phase are omitted from the energy analysis. Depending in what stage the analysis is made it is chosen the right option. The **Analytical Space Resolution and Analytical Surface Resolution** parameter provide important information used by the algorithm that generates the energy model. The default values for these parameters offer an optimum balance between energy model accuracy and processing time for most Revit models. When you increase the values for Analytical Space Resolution and Analytical Surface Resolution, the processing time required to create the energy model is significantly reduced. Reducing these values does not necessarily result in a more accurate energy mode. While the **Perimeter Zone Depth** considers the fact that the core of a building has heating and cooling loads that differ from the perimeter because it is not directly exposed to external weather conditions or daylight through windows. A typical perimeter zone depth is 4-5. Setting the perimeter zone depth is a valuable part of automatic thermal zoning, especially for buildings with large open plans or for early massing studies, like the case study. Finally, the **Perimeter Zone Division**, results in more accurate energy consumption estimates. For example, in the late summer afternoons, a west façade may encounter solar heat gain while the east façade does not. Perimeter zoning allows energy analysis of these perimeters to be handled separately.

Finalization of the model for energy simulation in cloud

Successively, the model was created with the described data, and the program did not present any error during this process. The result is shown in the 3 D model below:

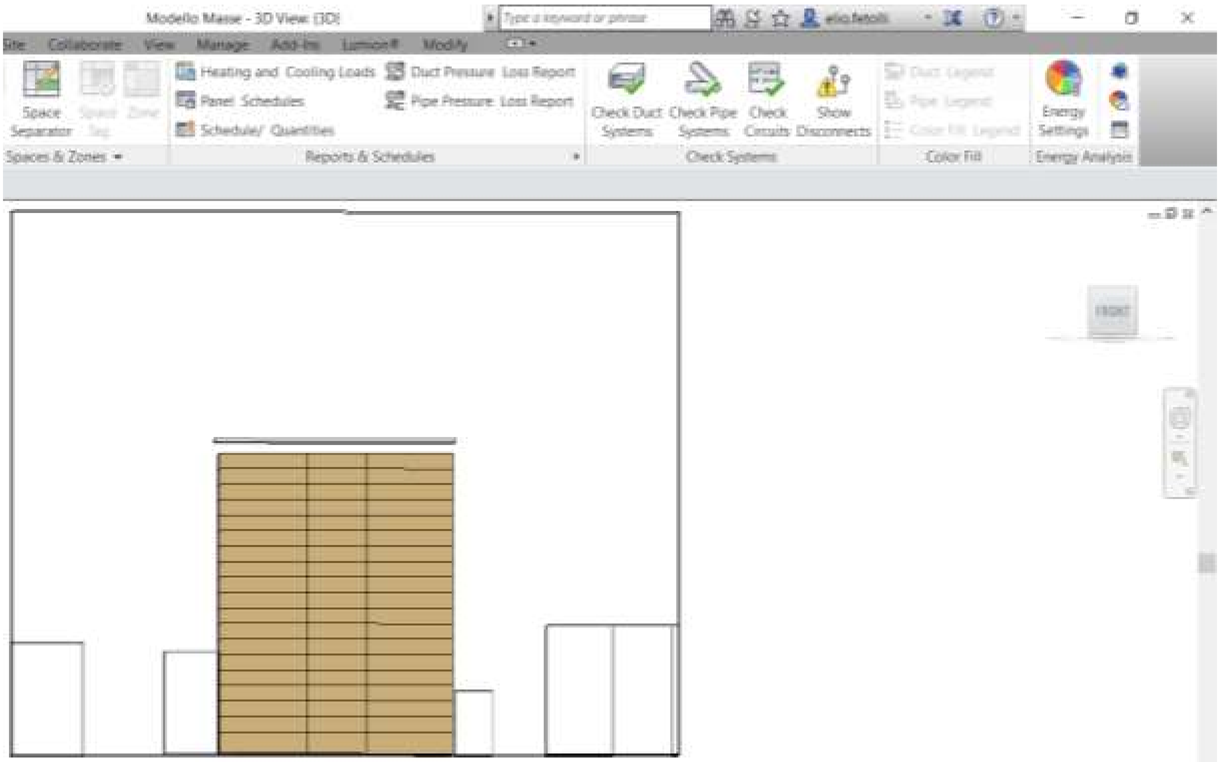


Figure 59 The final mass energy model divided in floors
SOURCE: author

Then after pressing the button run energy simulation, it was sent into cloud to run the necessary simulations.

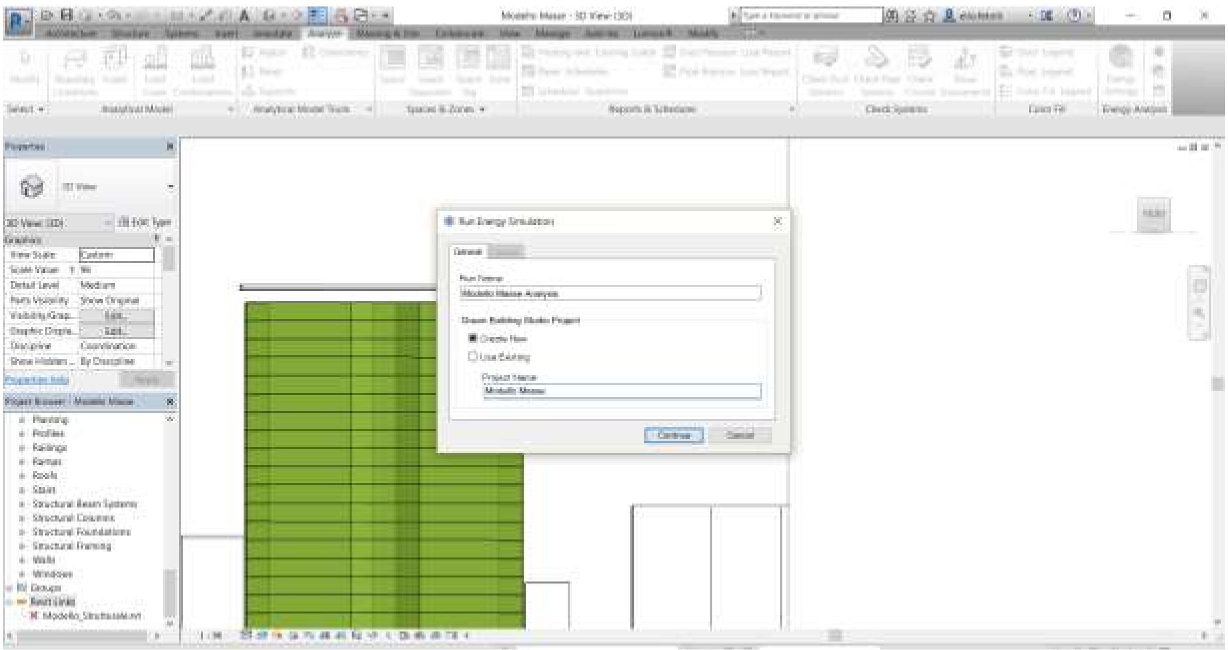


Figure 60 Mass model is sent into the cloud to make the simultaneous simulations

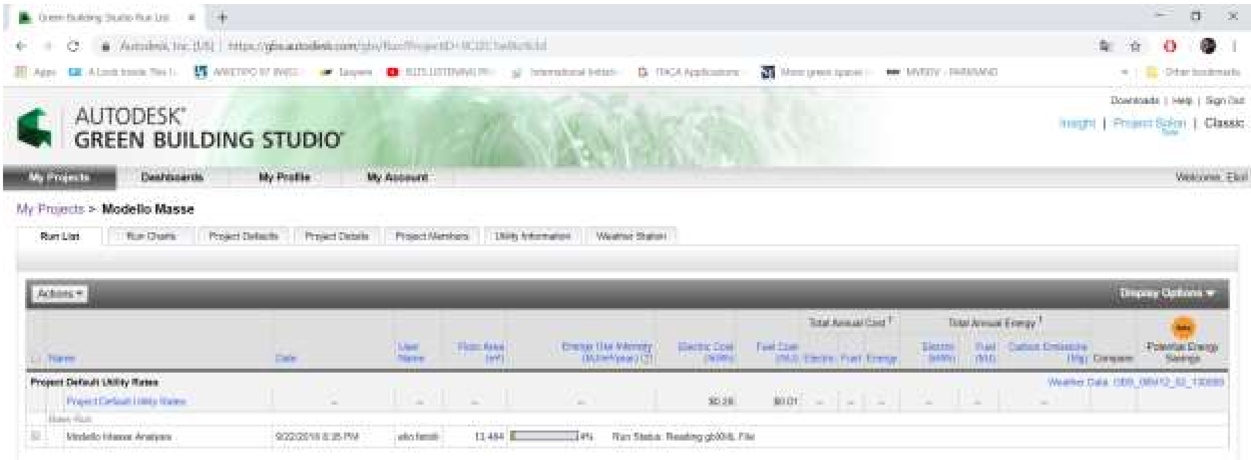


Figure 61 Initialization of the simulation process

Errors and iteration loop

Initially, the run resulted in errors due to model inaccuracies, this is a part of the iteration process of the workflow illustrated in the beginning of the chapter. It gives the possibility to the user to create a more accurate model, by finding the errors and then analyze it correctly in the cloud.

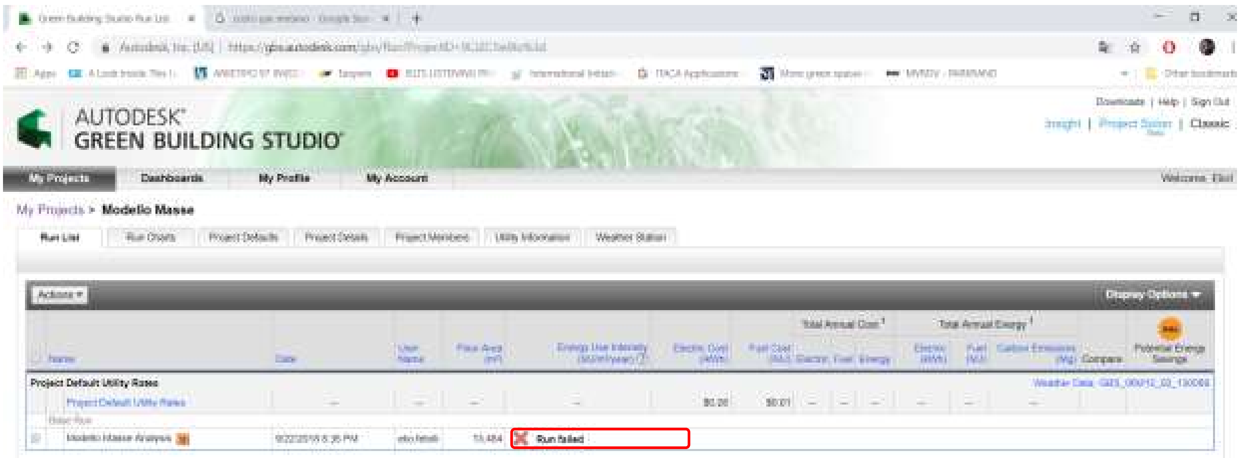


Figure 62 Inaccurate model determines a failure in running of the simulation

The model was then adjusted in order to make it adaptable for the simulation. Some changes in the construction phase parameters were made. Since the building mass was created with the existing phase and the simulation in the new construction, there was an internal conflict, which did not allow it to go ahead in analysis. The percentage of run completion increased in time and the end result was satisfying.

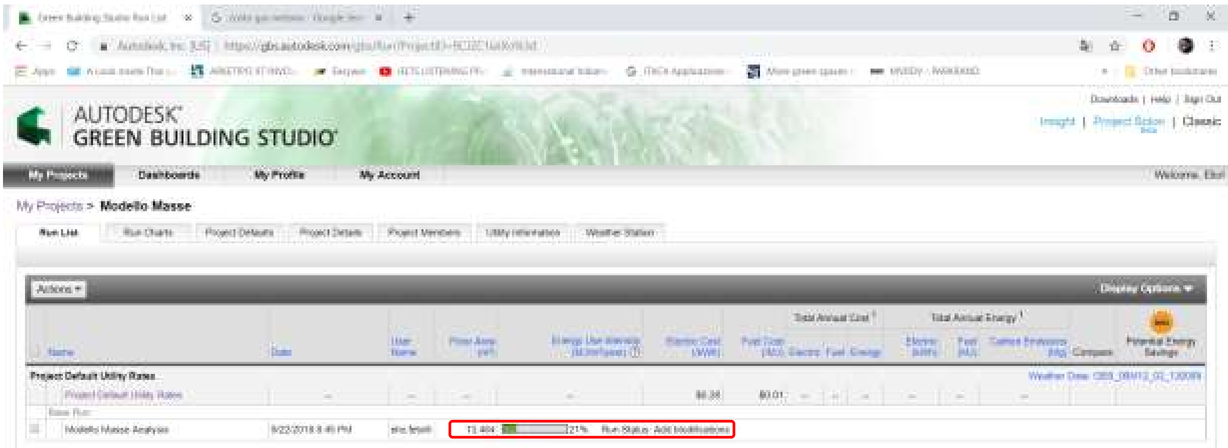


Figure 63 The model progress in cloud simulation after making changes

In the end of the cloud calculations, a notification pops up if the things have gone the right way, as in case of this model and the next step is the results confrontations and eventual possibilities for interventions in a further design phase. The results of this simulation are represented in the attachment A_3.3.1.3

Figure 64 The end of successful cloud calculations

[Materiali Rai\Simulazioni Energetiche\Modello Masse (1) Modello Masse Analysis.pdf]

3.4.2. Building Components Model

After the orientation of the model and creation of the masses is already done, next step of the flowchart consists in creating the building components part. The created model would do the energy simulation based on all the compounds. Starting from the creation of slabs for each floor, the enclosure and the roof to close it as the essential portions for the correct functioning of the program. A test model was simple, and it included only two floors and the roof, just to ensure that the program would start running. In the beginning as it was expected, the model presented some errors and the program was not able to create an accurate energetical model.

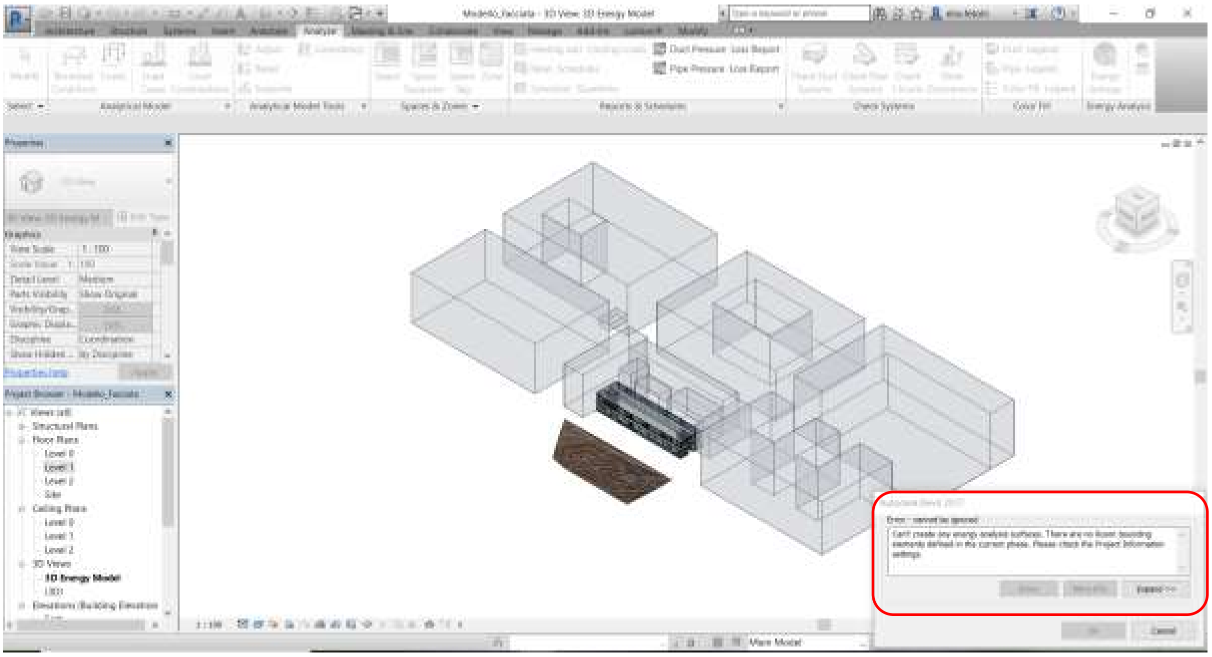


Figure 65 An unsuccessful attempt to create the right model.

The changes that were made regarded the geometry of the facility. Since the building components model is more complicated, and has many components, it needs a higher precision in the geometrical modelling phase. Some errors that regarded the joining of the elements with each other were spotted after inspecting the floorplan views and some other significant sections. Then it was again tested in the analyze tab section of Revit. After the test resulted successful, the model was built as the existing building with 18 floors.

Key operations for the successful result:

For each element of the building model, the relative thermal properties were specified. For example, for the façade the specifications were made concerning the type of glass and the frame. The figure below shows the glass thermal properties.

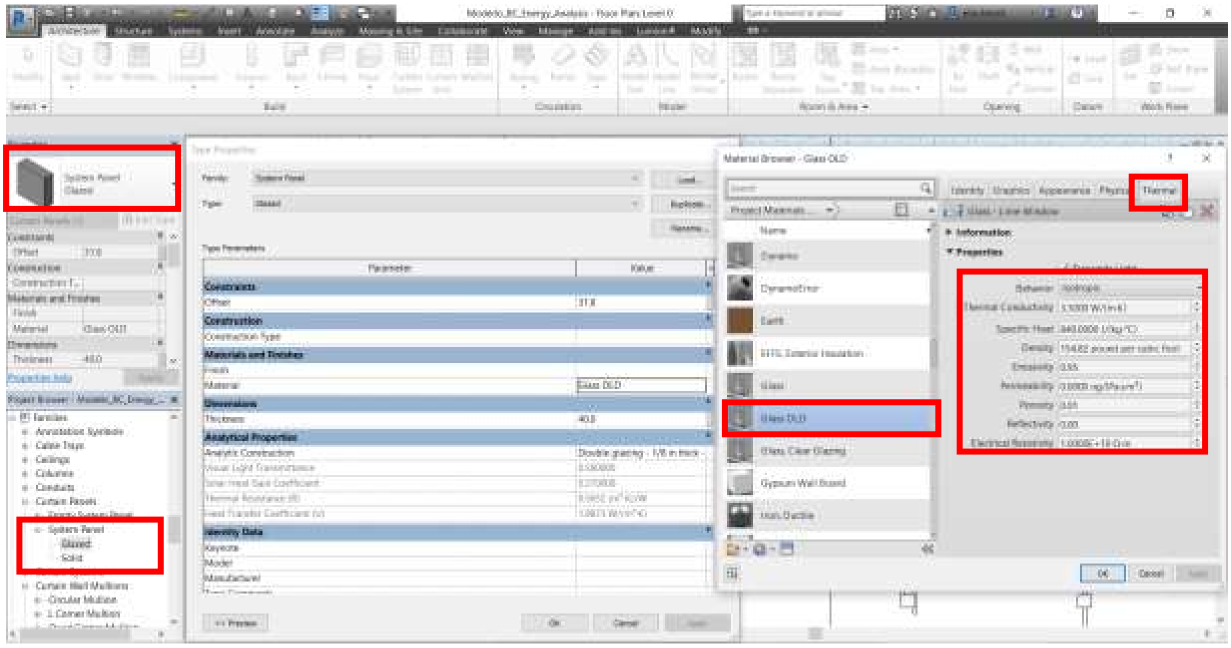


Figure 66 Glass thermal properties.
SOURCE: Author's work

In order to make a more accurate energy analysis the phase of construction should be specified to all the building elements. This specification does not alter the building components thermal properties, it only considers the phase of building the facility or the new interventions.

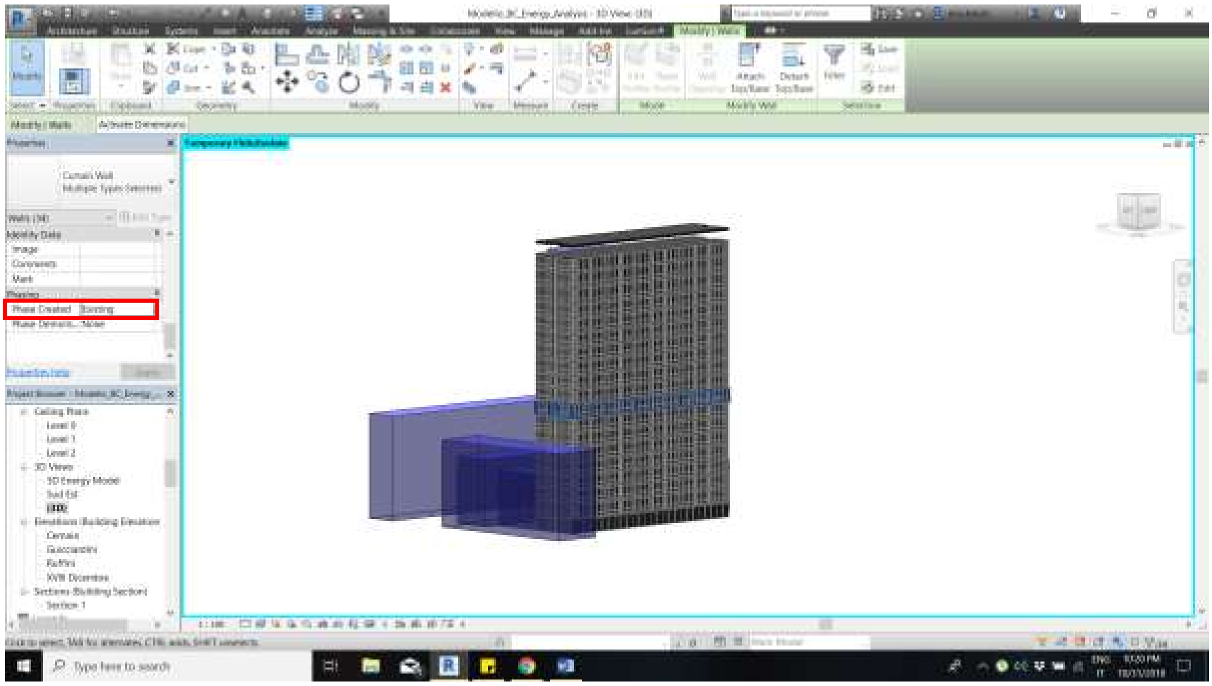


Figure 67 Representation of the model in the existing phase of construction

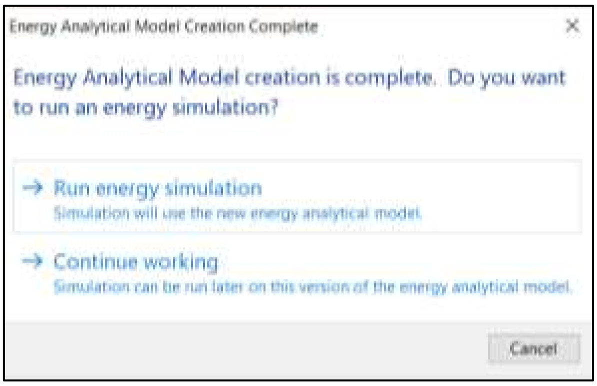


Figure 68 Notification of the successful model creation

Finally, the model was ran in the GBS cloud after the geometrical creation and the thermal properties specification. It is then inspected for any errors in the cloud simulation phase. The model resulted successful and the results are given in the attachment A_3.3.2.1.

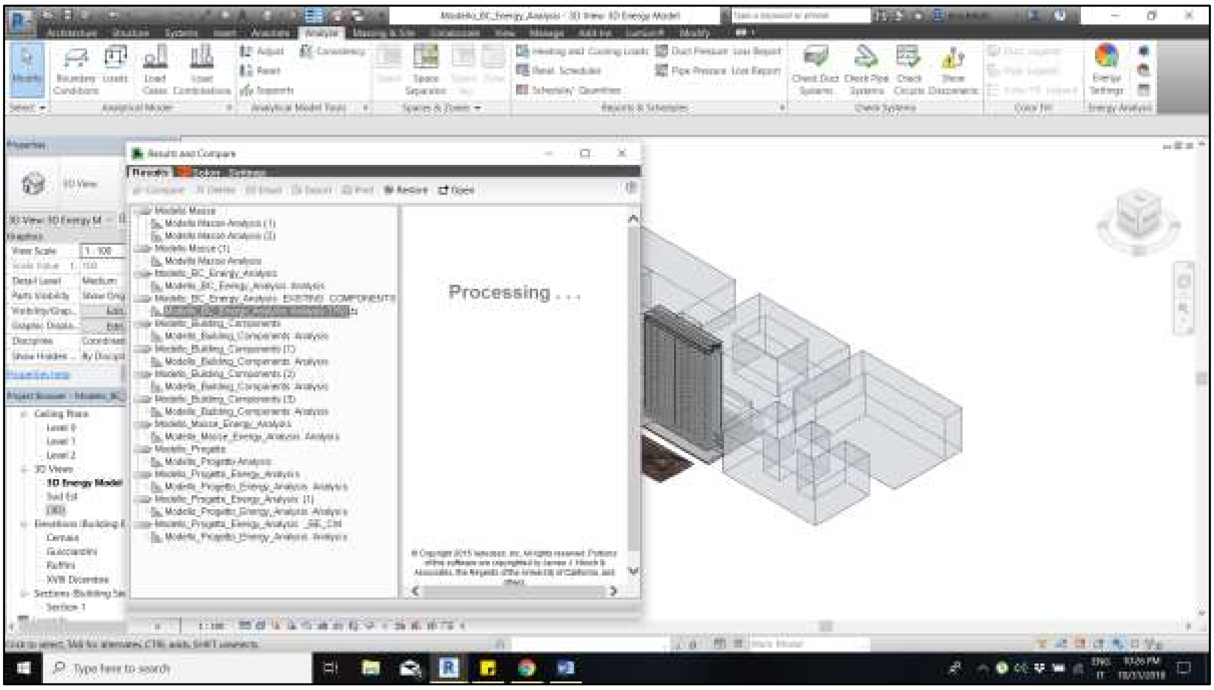


Figure 69 Interface of Revit for the GBS simulation

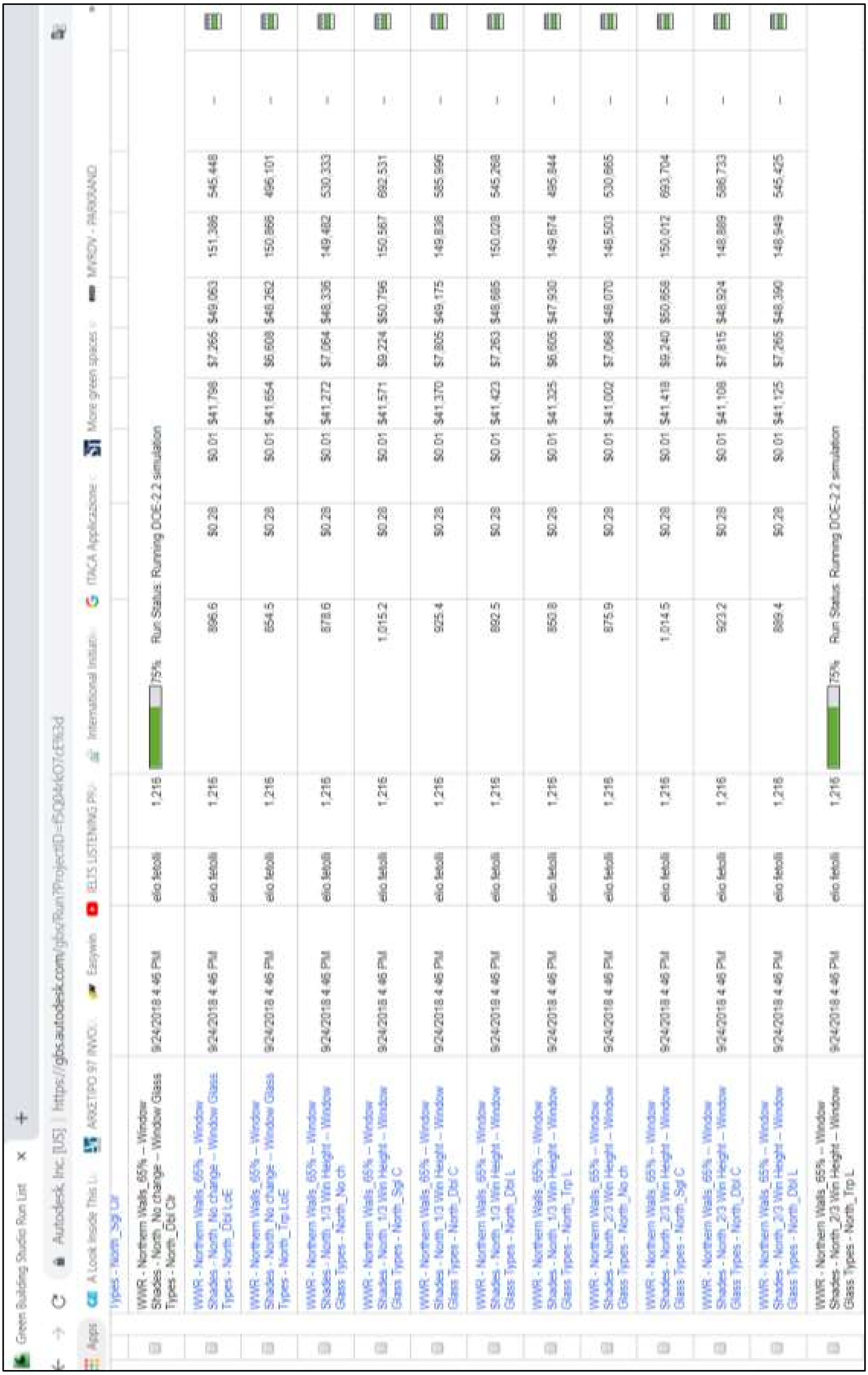


Figure 70 The overview of cloud simulations taken from the personal page in the Autodesk GBS Studio

3.5. Exporting for further analysis

To perform energy analysis using other software the model can be exported into gbXML file. Two options are available as described from the site of Autodesk[7]:

"Use energy settings: This method exports the energy analytical model created by Revit. **Use room/space volumes**: This method uses volumes defined in the building model based on rooms or spaces in the model. These volumes may not be as accurate as those created using energy settings".

The division of the space can be used also for the calculation of heating and cooling load determination. For this study purpose it is only worth to mention it, but no detailed analysis is made.

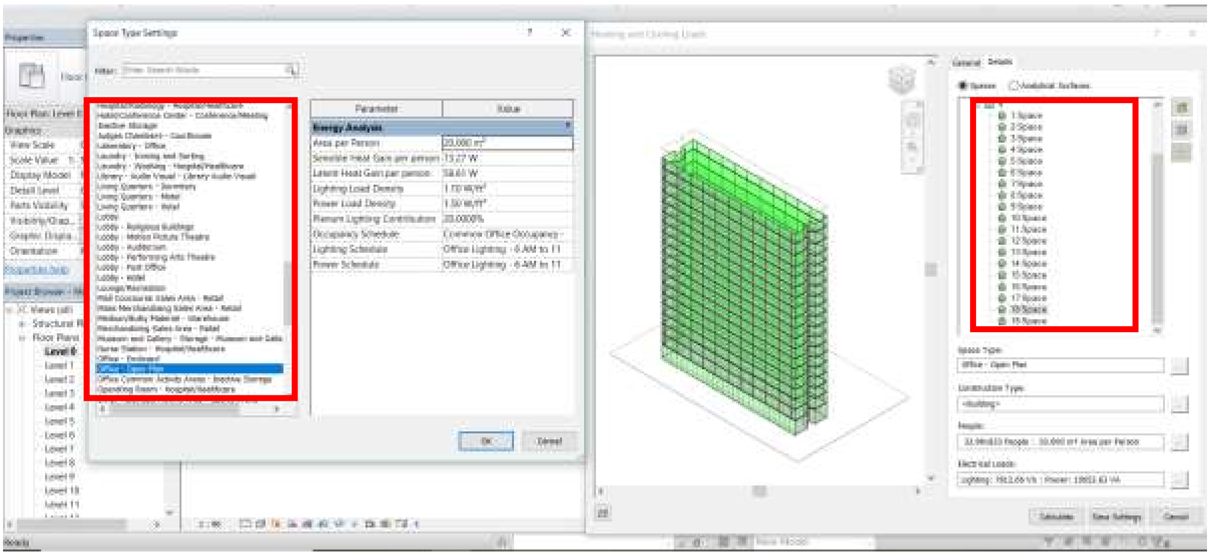


Figure 71 Possibility to make heating and cooling load determination

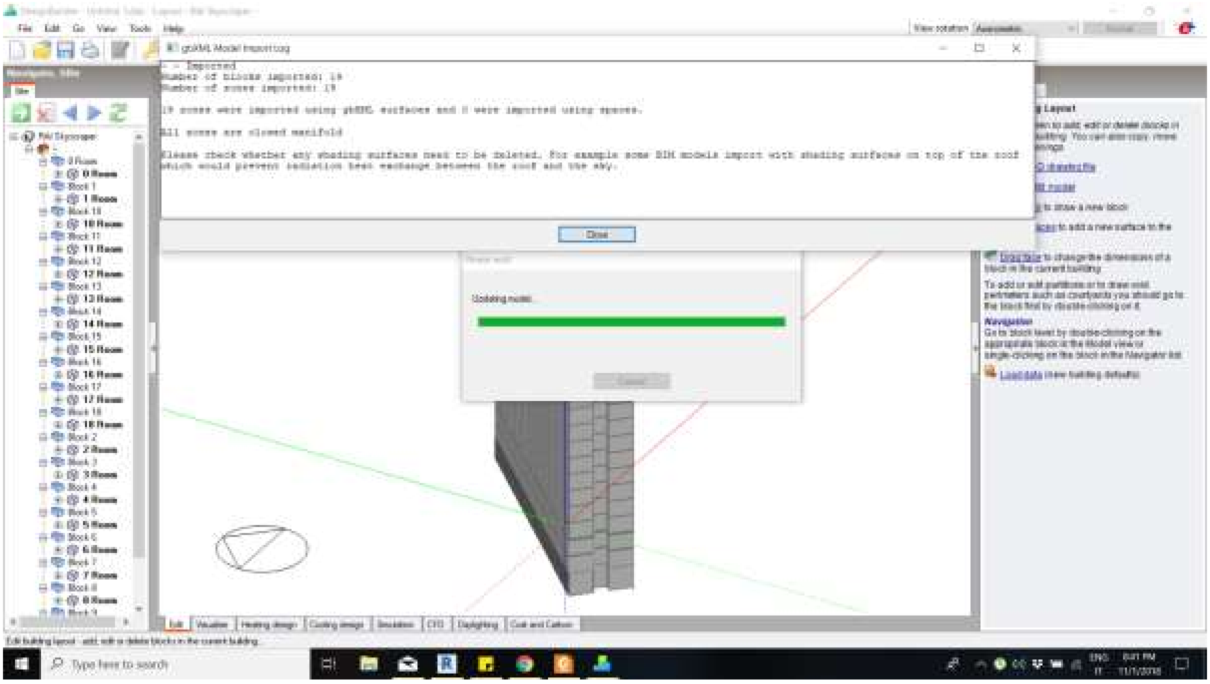
In the case study, the separation is made automatically from the program considering the whole building as a unique thermal zone.

3.5.1. Why using the format gbXML?

The format gbXML is used for the exchange of information allowing interoperability because of following advantages:

- Allows disparate 3D building information models (BIM) and architectural/engineering analysis software to share information with each other
- Allows intelligent solutions for the design, certification, operation, maintenance, and recycling of building information models
- Uses a standard schema language (XML) so that major industry applications can import and export project information no matter the vendor, device, or software platform
- Has the industry support of leading 3D BIM and analysis software vendors and has been the defacto industry standard schema for over 15 years

Since it was possible to use a trial version of the Design Builder software, an integrated plugin to Revit made it likely to import the model directly to DB. In order to make further analyses of the model the gbXML schema works with DB software.



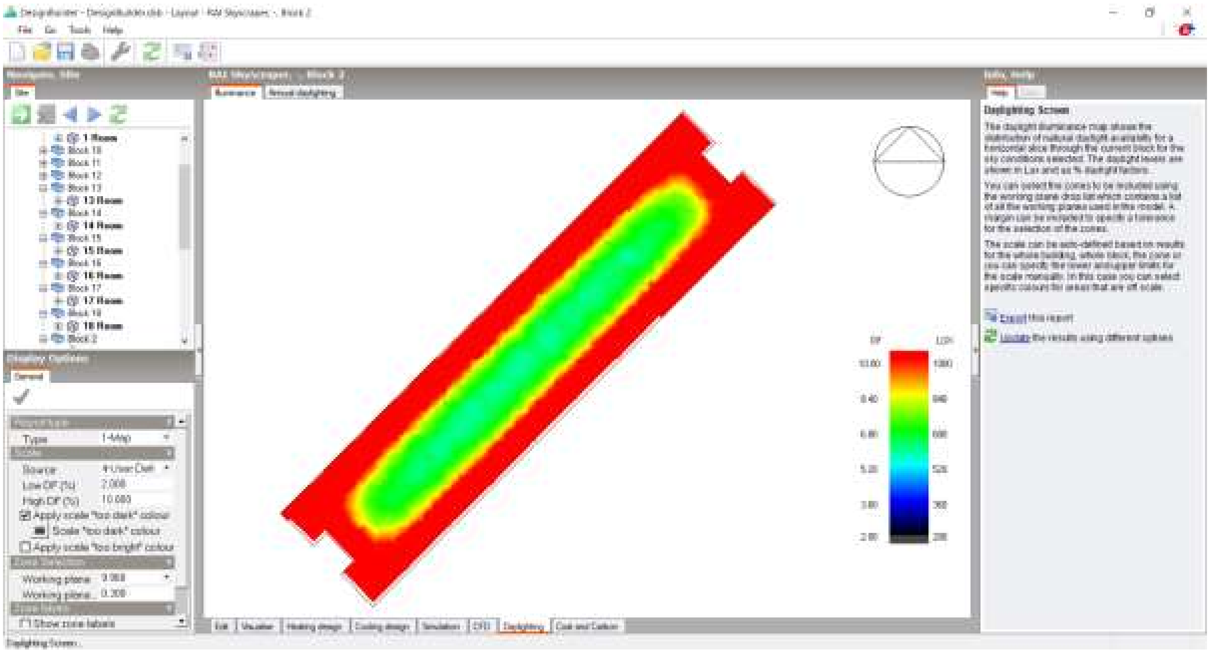


Figure 72 Daylight analysis DB

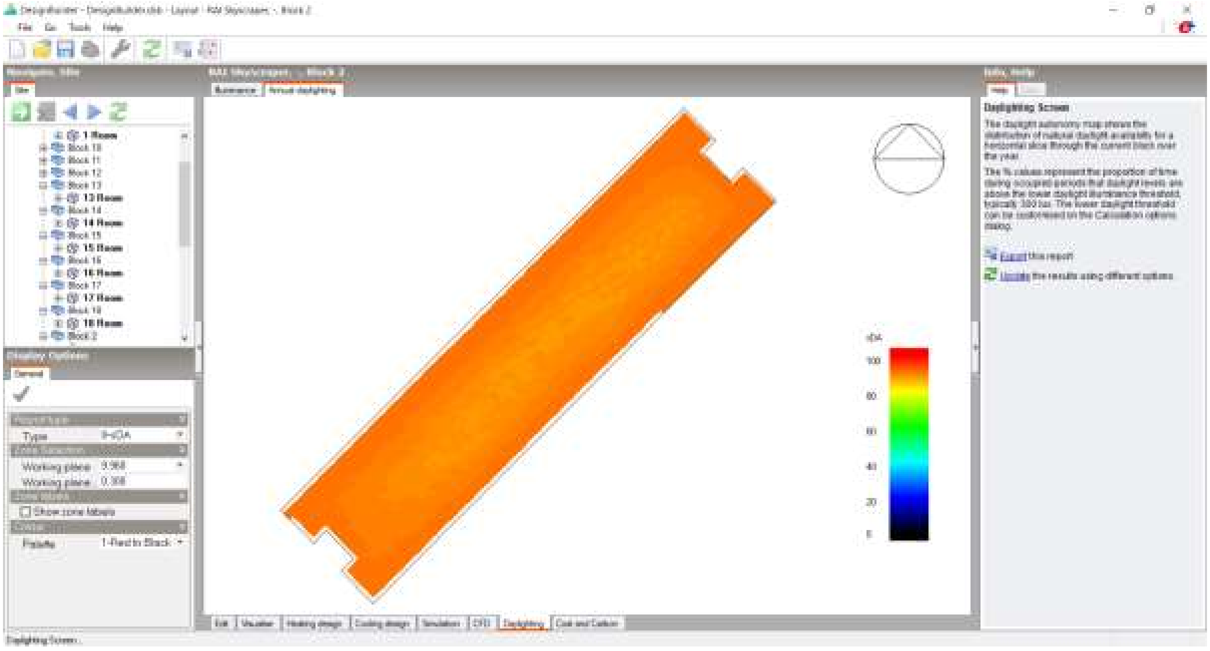
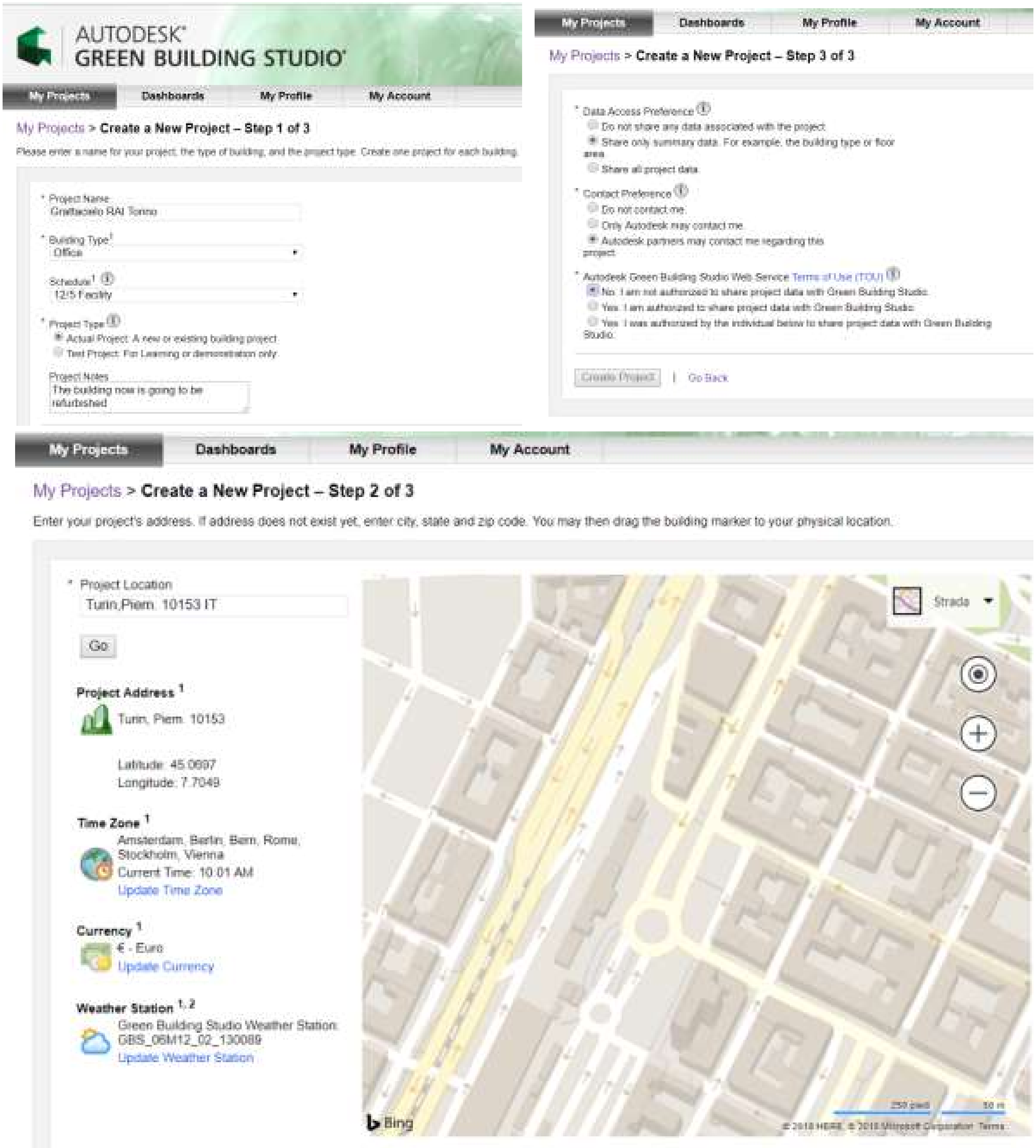


Figure 73 Distribution of natural daylight

GBS Creation of default file

Here it represented the creation of the file in GBS online.

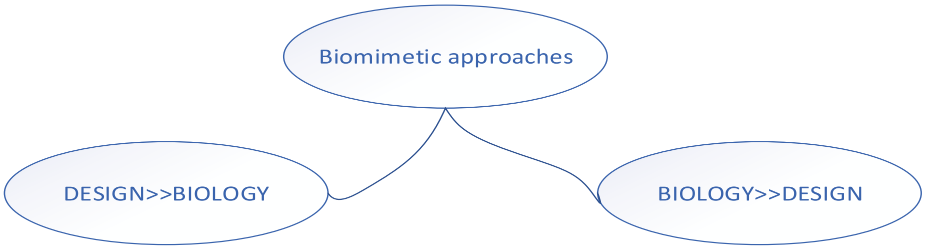


4. The Living Architecture as part of a biomimetic approach in design.

"Nature is by far the richest source of inspiration and knowledge that we have".

4.1. The Living Architecture related to biomimicry.

Living Architecture is a branch of architecture that focuses on the integration of natural processes into the building. These processes include catching, storing and filtrating water, harvesting the energy of the sun and wind, purifying water and processing the nutrients. To implement the idea of a living organism in a building, the system must be seen as a whole, and the technological elements should be thought as interacting portions with the natural ones. Living architecture is important because among all the benefits, it considers biophilia, the documented health profits associated with being in touch with the living systems in the built environment[8]. The living architecture tradition was first developed in Berkeley, California, with Christopher Alexander[9] as the main protagonist.



SCHEME 2 The two biomimetic approaches

The **biomimetic architecture** includes the LA since it focuses on understanding the natural forms systems and processes. This understanding can be utilized in two different ways, either having an example in nature and imitating it in a new project or finding an example in nature which better fits the design requirements. The levels of a biomimetic analysis are different depending on the study purpose. "Incorporating an understanding of how the living world works and what ecosystems do into architectural and urban design is a step towards the creation and evolution of cities that are radically more sustainable and potentially regenerative".[29] Zari also points out the importance of humans as decision makers in the system by saying: "Humans are undoubtedly effective ecosystem engineers, but may gain valuable insights by looking at how other species are able to change their environments while creating more capacity for life in that system." So it is on us to do what we have to do, to survive.

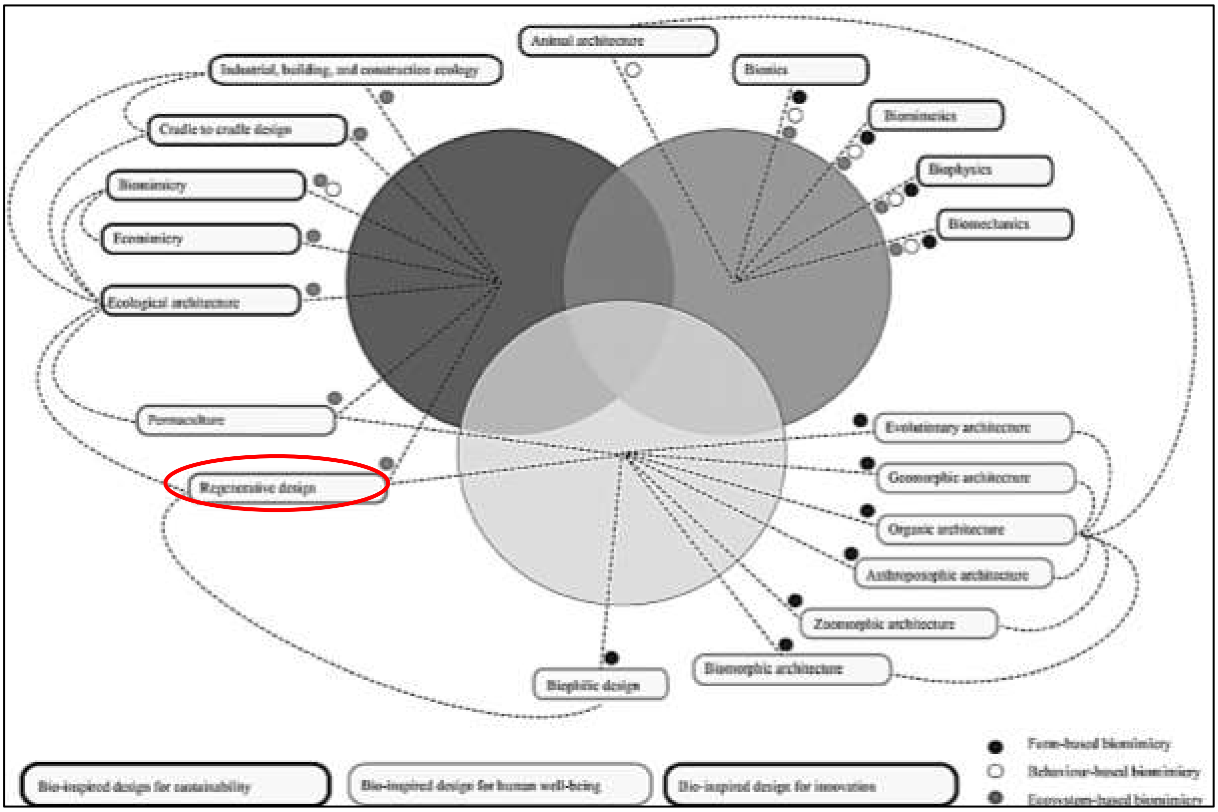
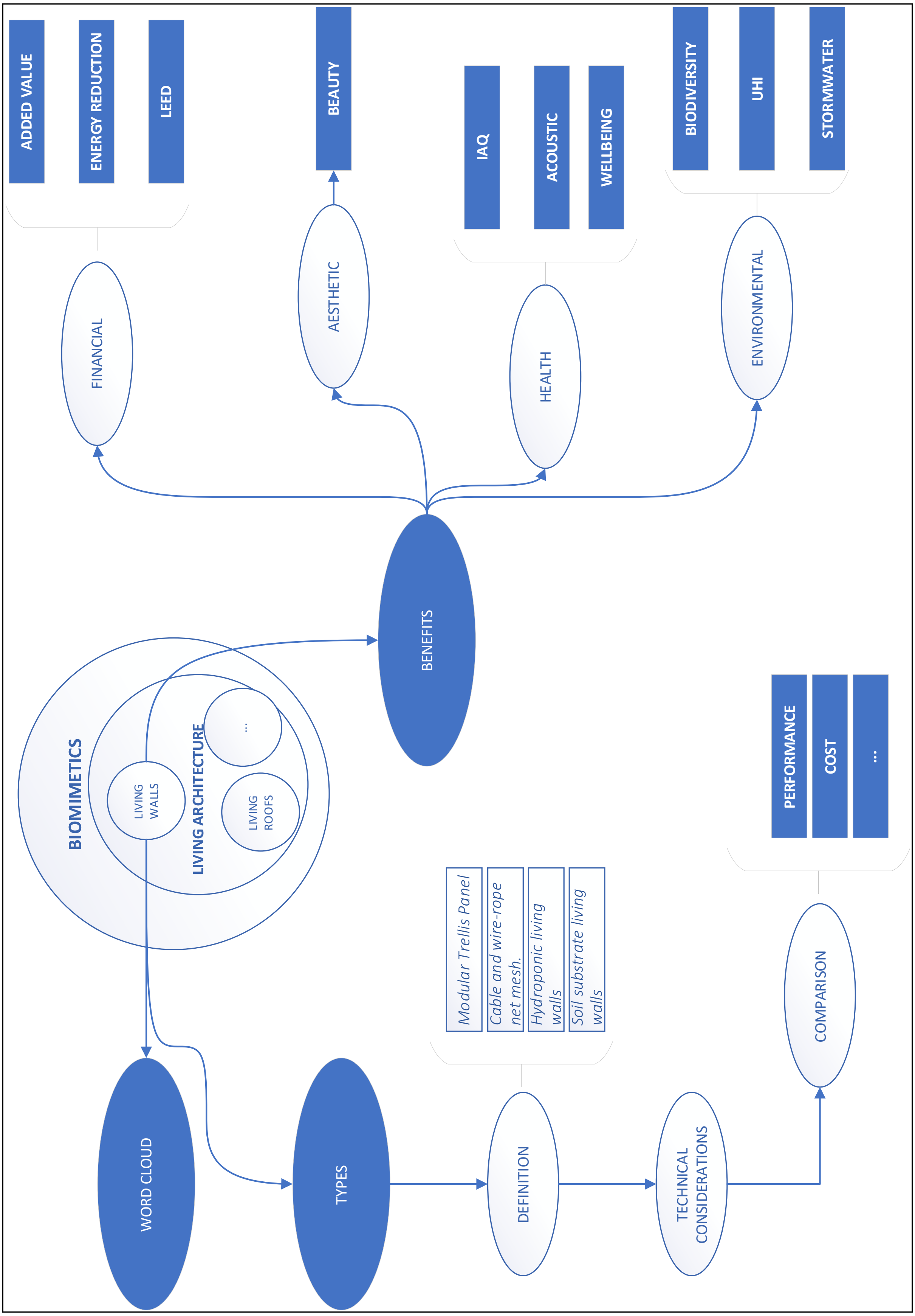


Figure 74 Incorporating biomimicry into design.
SOURCE: Regenerative Urban Design and Ecosystem Biomimicry. M. Zari

[29] Regenerative Urban Design and Ecosystem Biomimicry. M. Zari



SCHEME 3 The schematic overview of the chapter flow

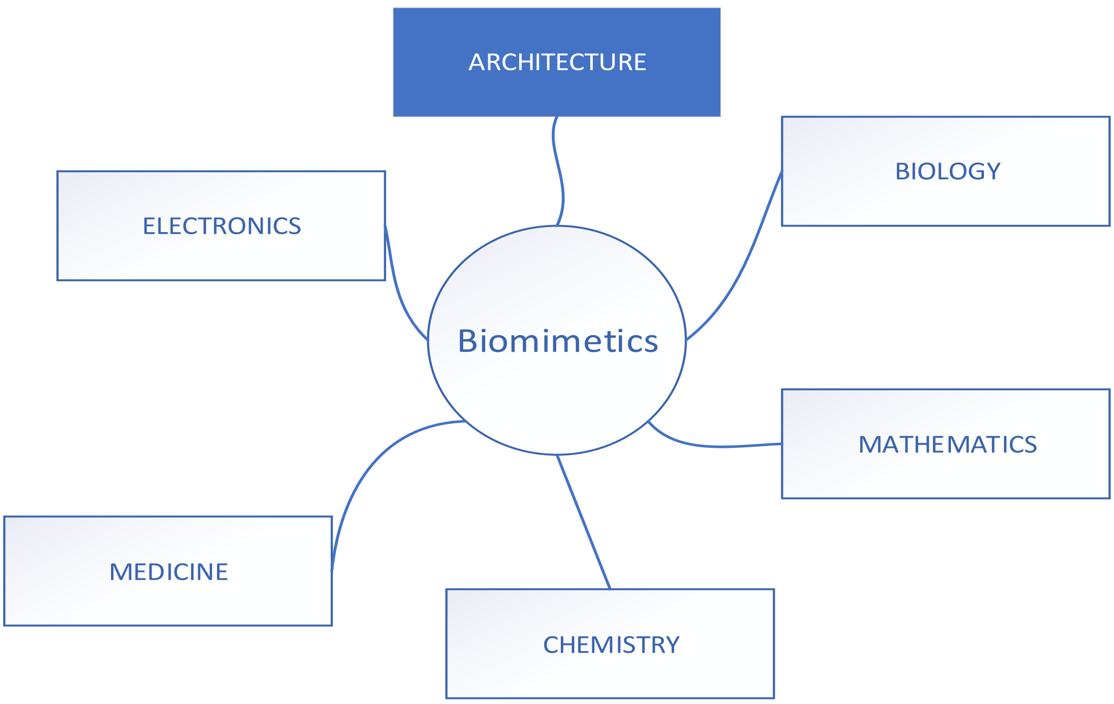
4.1.1. Biomimetics in architecture, definition and significant examples.

The term 'biomimetics' was created in 1950 by biophysicist Otto Schmitt, who wanted to invent a device that replicated the propagation of nerves in living organisms. Biomimetics has been popularized by writer Janine M. Benyus with the book "Biomimicry: Innovation Inspired by Nature" in 1997. In her book she describes in detail how science is studying the best ideas of nature to solve the most difficult challenges of our millennium. "Biomimicry ushers in an era based not on what we can extract from nature, but on what we can learn from her. This shift from learning about nature to learning from nature requires a new method of inquiry, a new set of lenses, and above all, a new humility"[30]. As it is described in the official webpage of the institute founded by the writer, the biomimicry can be implemented in a wide range of activities.

Figure 75 The life circle SOURCE: Biomimicry institute

"Because of its broad range, biomimicry contributes, both practically and philosophically, to many of the eco-design paradigms devised in the last 30 years, including the Natural Step, Natural Capitalism, Cradle to Cradle, Ecological Design, and Living Building Challenge"[31].

Biomimicry is not the same as biomimetics or bio inspired. It is a multidisciplinary subject that englobes many fields. Biomimetic architecture is a branch of the biomimetic approach as represented below in the scheme.



SCHEME 4 The field of architecture together with other fields object of the multidisciplinary biomimetic lenses

[30] Janine M. Benyus *"Biomimicry: Innovation inspired by nature" 1997.*
[31] www.biomimicry.org a biomimicry primer.

Biomimetic architecture is a contemporary philosophy of architecture that seeks solutions for sustainability in nature, not by replicating the natural forms, but by understanding the rules governing those forms. "It is a multi-disciplinary approach to sustainable design that follows a set of principles rather than stylistic codes.[32]"

Over the decades, the field of biomimetics has shifted from looking towards nature for overall shape towards a more functioning by understanding view of processes and systems. In fact, the approach has three levels: Organism behavior and ecosystem as represented in the scheme on the right.

SCHEME 5 Biomimetical levels

It is used according to the design problem necessity. Because if mimicking of organisms only of a specific feature, rather than a whole system has the risk that biomimicry becomes technology that is added onto buildings rather than being integral to them. The efficiency of a biomimetic approach is reached when collaboration between experts of different fields is accomplished and the solution is integral.

Some examples of biomimicry in architecture

Figure 77 La Sagrada familia A. Gaudì. Mimicking the form of the forest that invites prayers.
Source: All Canada Photos / Alamy Stock Photo

Figure 76 the biomorphic Kunsthaus Graz, inspired by nature but not mimicking it 100%
SOURCE: LOOK Die Bildagentur der Fotografen GmbH / Alamy Stock Photo

Figure 79 The Taichung Theater, Taiwan inspiration from theformation of rocks, caves and the transience of water
SOURCE: Chao-Yang Chan / Alamy Stock Photo

Figure 78 The Eden Project, near the thamlet of Bodelva in Cornwall, UK. Inspired by the shape of soap bubbles
SOURCE: Caitlin Mogridge/Redferns via Getty Images

[32] University of Nairobi. Research 303.

4.1.2. Benefits of the Living Walls

According to recent studies Green Walls help buildings become more energy efficient which leads to a decrease in carbon emissions. They also mitigate the UHI (urban heat island) effect, absorb and filter stormwater, reduce pollution and act as carbon sinks. They also preserve the biodiversity of plants and animals in the city, acting as attractive oases to many species.

Figure 80 The vertical forest SOURCE: Stefano Boeri Architects

Biodiversity

If you were to go back in time the ecosystem on earth was very diverse, containing many different plants and animal species. Modern cities and croplands have severely reduced that biological variety. The loss of biodiversity is caused and affects directly the people as it can be observed in the figure. A possible remedy can be found in the LWS which can be considered as a **mimicry** of natural vertical habitats. According to a study published in the journal Global Ecology and Conservation [10] the potential of LWS is enormous. The outdoor living walls can be viewed as mini ecosystems; the incorporation of such a variety of plant species attracts many beneficial organisms such as butterflies, bees, ladybugs and humming birds.

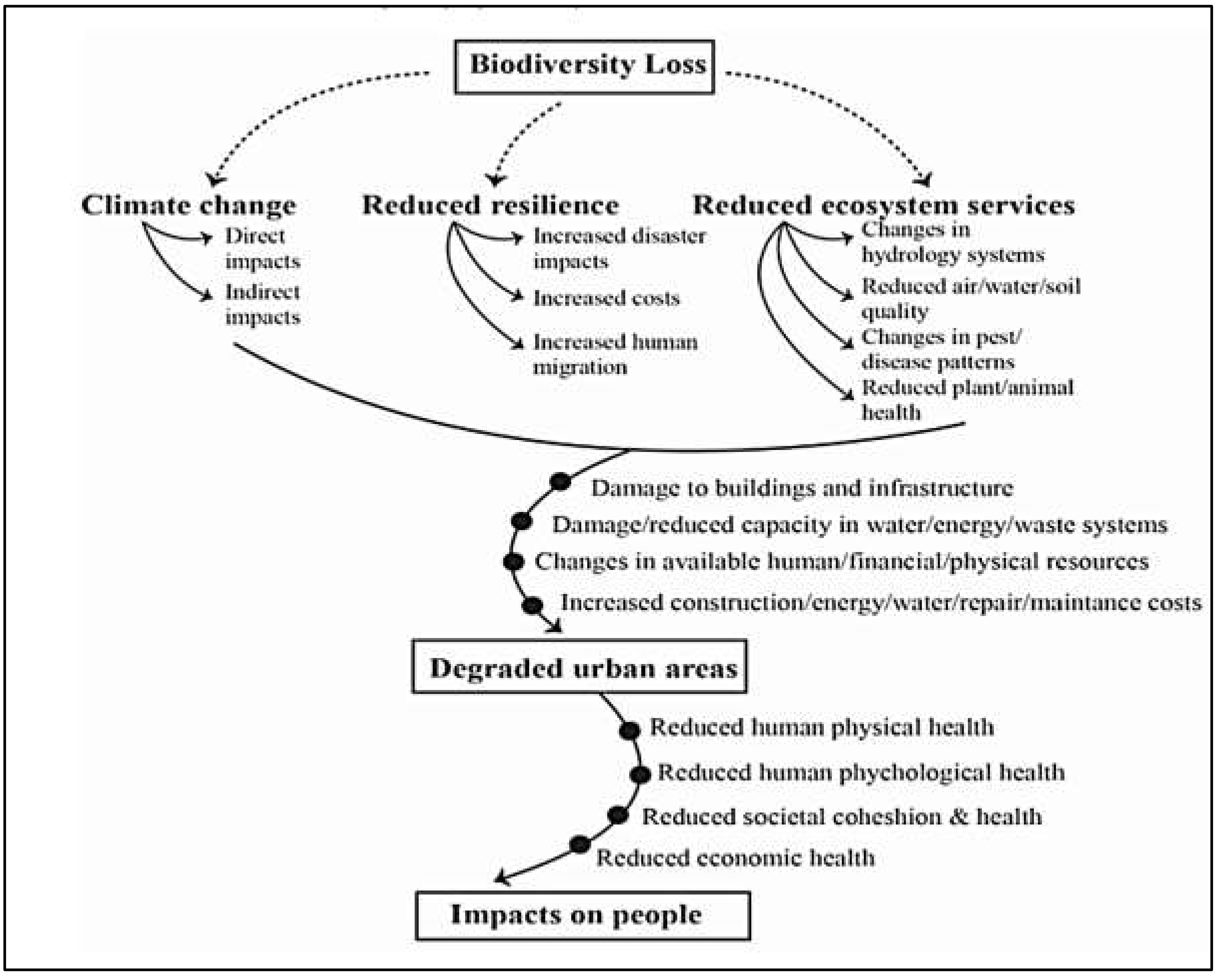


Figure 81 How the loss of biodiversity impacts us. SOURCE: The importance of urban biodiversity – an ecosystem services approach

In the end of her article[11] Zari concludes that: "Cities must become a key player in global efforts to conserve and restore biodiversity. At the same time if the goal of urban design is to create or retrofit cities so that they support the wellbeing of people, the support and regeneration of urban biodiversity must be integrated into design decision making and interventions"[33].

Urban Heat Islands

This problem is documented long time ago in the report sent to the Club of Rome[34][3] and its effects on the environment are not negligible. The urban heat island effect is defined as a metropolitan area or locality which has a higher temperature than its surroundings; especially (in full "urban heat island") an urban area having a sustained higher temperature, owing to heat generation by vehicles and energy consumption, and to the absorption of sunlight by roads and buildings. [12]

[33] M. Pedersen Zari. *The importance of urban biodiversity – an ecosystem services approach*. 2018
[34] D. H. Meadows. *The limits to growth (Italian Translation).*Milano. A. Mondadori Editore. 1972. P. 65

How Do Urban Heat Islands Form?

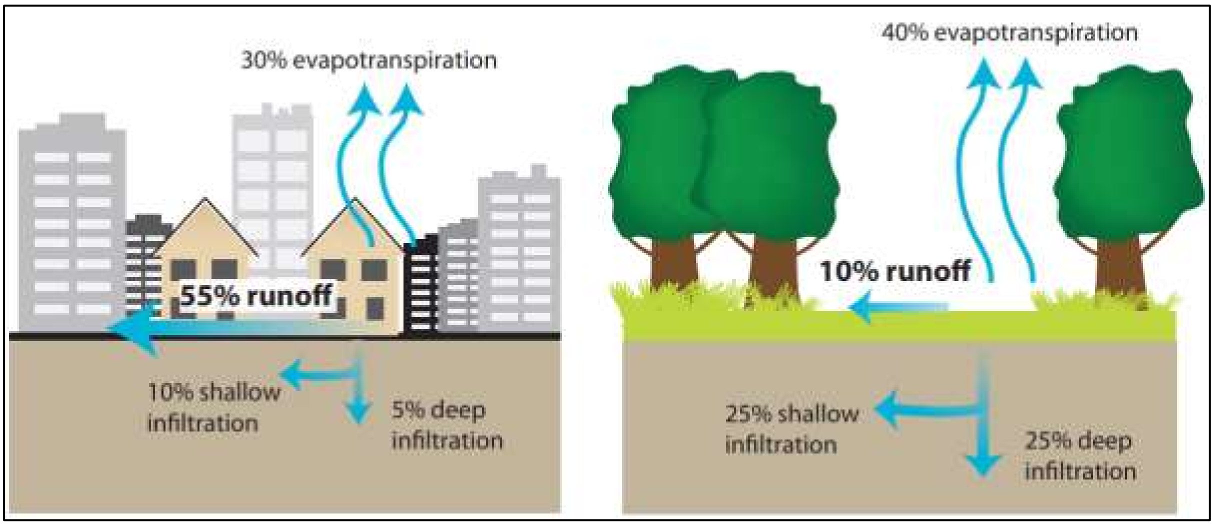


Figure 82 Highly developed urban areas (right), which are characterized by 75%-100% impervious surfaces, have less surface moisture available for evapotranspiration than natural ground cover, which has less than 10% impervious cover (left). This characteristic contributes to higher surface and air temperatures in urban areas. SOURCE: EPA

A large portion of this heat comes from the multitude of hard surfaces, including exposed walls, which radiate the sun's energy. Vegetation has been shown to reduce this effect and the negative impacts it has on life quality.

Why Do We Care about Urban Heat Islands? Although the positive effects are present, most of the effects are negative and include:

- Increased energy consumption
- Elevated emissions of air pollutants and greenhouse gases
- Compromised human health and comfort
- Impaired water quality

Fortunately, urban heat island mitigation strategies, for example, trees and vegetation and green roofs which are the focus of research generally provide year-round benefits, or their winter penalty, such as that from cool roofs, is much smaller than their summertime benefits.[13].More information ca be looked upon the webpages on how to mitigate this phenomenon in the table of the attachment A1_4.1.2.:*Additional resources on urban heat island SOURCE: EPA report*

Stormwater

Green walls naturally absorb and filter stormwater. It is also possible to irrigate them using collected rainwater. The roots, and microorganisms living around them, utilize and remove pollutants found in the water. Excess water is eliminated through the process known as evapotranspiration. In recent years, the combined use of vertical greening structures and green roofs has been increasingly adopted as "bioclimatic" design to complement (or partially replace) urban grey drainage infrastructure systems .Various studies are made regarding the effectiveness of the greenery systems for the retention of the stormwater, but most of them consider the combination of green roof with the vertical façade and not vertical green separately.[14]

Indoor Air Quality

According to modern scientific research,[15] indoor environments may be as much as ten times more polluted than the outdoor environment. This is known as "Sick Building Syndrome"[16].

It is stated by an important study[17] that the average person spends over 90% of their time indoors. During this time people suffer the consequences of indoor air pollution not having also a good IAQ. This includes toxic fumes such as formaldehyde, VOCs, trichloroethylene, carbon monoxide, benzene, toluene, xylene, and countless others[18].

The remedy to the problems stated below can be found in plants. Nature has many examples of natural green walls, living walls or vertical gardens. As plants grow they absorb greenhouse gases from the atmosphere and store it in their tissues. According to a study conducted by cell press reviews [19] is that all plants absorb and clean pollutants from the air. Recently, more accurate experimentation simulating the long-term exposure of foliage to typical indoor concentrations of air pollutants highlighted that stomatal (dependent) absorption is 30–100 times higher than the amount passively adsorbed through non-stomatal deposition[35]. Certain species are more efficient than others. A single potted plant removes a portion of these airborne toxins and with each additional plant this increases.

A green wall can contain over a thousand plants, all which filter air and in addition create energy-rich oxygen. Implementing the VGS also in the internal environment remediates the IAQ and brings many compensations and profits for the occupants. This way the occupants can express also a level of comfort regarding the internal ambient.

Many reports regarding the environment and the national geographic website [20], show that the rainforests are cut down and burnt at an alarming rate with over 6000 square meters of rainforest lost every second equivalent of 6 ha every 10 seconds. Experts estimate that we are losing 45 plant species every single day due to rainforest destruction. This equates to over 16,000 species extinction a year! Including species that are threatened in their natural habitat in the design of VGW can be a protective mean against this massacre.

[35] Plants for Sustainable Improvement of Indoor
Air Quality, Pg.1

Building protection

A green wall acts as a kind of protective barrier which shields a building from solar radiation and heat penetration. This reduces the demand on cooling systems. In winter living walls provides an additional layer of insulation keeping the cold out and warmth in. These features act to reduce the carbon footprint of a building. [21]

They do this by reducing temperature fluctuations of the envelope. A constant flux in temperature leads to the expansion and contraction of building materials. This results in cracks, fractures and general deterioration.

The waterproof living wall panels and the exterior envelope are separated by a layer of air, allowing the building to 'breath'. The system is very similar to rain-screening technology; keeping rain off the building while still allowing moisture to escape.

Covering an exposed vertical surface with a green wall shields it from precipitation and wind as well as from harmful UV radiation and corrosive acid rain. This in turn increases the integrity and longevity of a building's exterior.

Added Value

Greenery improves the visual, aesthetic and social aspects of the urban area, which have a high influence on the economic value of a building or neighborhood and contributes to enhancing human health [22]. Today, people are looking for concept of green where they live. This situation is increasing prices of project which have more green spaces. This is an enduring benefit investment and the initial costs in realization should not underestimate the long-term paybacks, and the unquantified profits in implementing the green. A further examination of the paybacks in economic terms is object to be analyzed focusing on the energetical benefits, but it does not enter in the merit of this thesis.

Energy reduction

Studies [23]have shown that the surface of an exterior green wall is cooler than an exposed wall, therefore considerably less heat is radiated inward. Research showed that the humid climates of Hong Kong can achieve substantial benefits of a maximum temperature decrease of 8.4 °C [24]. Also, the effect of shading during the summer is very decisive in reducing the cooling loads. According to a study conducted by the National Research Council Canada [25] the shading effect of vertical greenery systems reduces the energy used for cooling by approximately 23% and the energy used by fans by 20%, resulting in an 8% reduction in annual energy consumption. This result comes partially also through the process known as transpiration. Plants cool their surrounding environment slightly. With each additional plant this increases and therefore a green wall, with hundreds of plants, can reduce the temperature of a room by anywhere from 3 to 7°C [26]. According to a study conducted by the University of Seville [27] the cooling effect of the living wall was proven, with an average reduction of 4°C over the room temperature though maximum decrements of 6°C have been observed in warmer conditions.

During winter some living wall system act as extra insulation. There is an additional layer of air between it and the wall which reduces the amount of heat escaping and cool air coming in. A study conducted by Perini [23]shows the potential of vertical green layers on reducing the wind velocity, thanks to a stagnant layer around building facades.

Wellbeing and health

Urban green is recognized as remedy for the stress reduction with a high number of discussions[28], publications and research papers [29] that confirm its benefits. Three important factors that are pointed out in a research paper [30]are:

- Distance – The closer open green spaces are to one's dwelling, the more often one will visit them.
- The visit – Spending time outdoors in urban open green spaces seems to be the most important single factor affecting the levels of stress in this study.
- Accessibility – A dwelling with direct access to a green yard or a garden of its own seems to be the optimal situation.

These studies need to be also put into practice and several papers have examined reasons that prevent the policy makers for implementing these practices, even though the benefits are visible. Among all

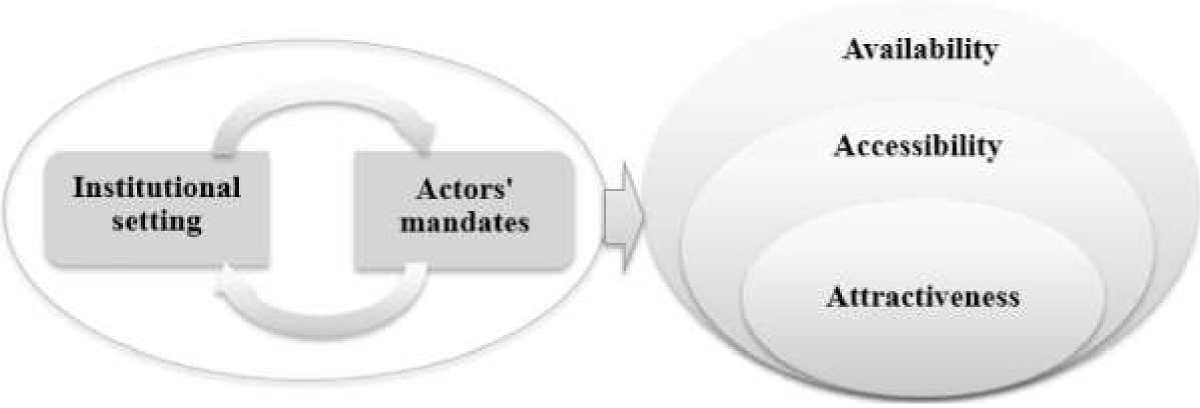


Figure 83 Figure 21The feedback loop between the actors' mandates and the more general institutional setting influencing the potential availability, accessibility and attractiveness of urban green spaces. SOURCE:[10]

of them there is an institutional context that is associated with barriers preventing the UGS provision. The researches have pointed out three levels for the UGS. Availability, accessibility, attractiveness. First a UGS must be available and built in a specific location that is accessible for the users to judge if it is attractive. The VGW placed in the façades of the high buildings accomplish the first level and a careful design can also make them accessible and attractive.

Beauty

When visiting botanical gardens, taking a stroll in a park or hiking through a forest it is easy to see that nature has come up with a huge variety of colors, textures, patterns and sizes. By utilizing this diversity and incorporating many species of plants it is possible to create living art. Architect Luciano Pia has created a living art with the modern condominium in Turin. The living example of a biomimetic approach into design which has created a stunning outcome is the 25 Green Area (Area 25 verde). The architect used the knowledge of botanists in the selection of plant species and integrated them harmoniously inside and outside the building complex.

Figure 84 A close up of an internal courtyard thatbrings the ambient of a forest inside the condominium. Location 25 Verde Torino

Designing a green wall which is diverse, eye-catching, intriguing and simply a pleasure to look at is a complex task. It requires strategic planning, in-depth knowledge of countless plants species, a strong eye for design and a whole lot of creativity! This is the case of this building complex, which immerses you in a deep connection with the nature.

LEED Credits

Green, Living Wall Design Considerations are discussed in the USGBC courses[31]. The design of VGW can be used to earn additional LEED® credits. LEED®, which stands for the Leadership in Energy and Environmental Design, is an internationally recognized green building certification system. The use of this typology is very important for the environment and the agency promotes it with extra LEED ® credits. LWS qualifies directly for two credits and helps gain an additional thirty points.

4.1.3. Examples of completed and ongoing projects worldwide.

The use of LA can be noticed in many applications of different scale. Starting from that urban, including the infrastructure and city squares, then perpetrating in the building scale exterior as well as interior. In this section some significant projects of Living Walls are represented.

Urban scale

A typology of LV is developed by Patrick Blanc[36]. It is defined as modern living wall and has special characteristics. Among all his realizations, an example of urban regeneration is chosen. The project details are showed, and the sequence of its construction is illustrated in the four images that follow.

Project Name: Pont Max Juvenal
Location: Aix en provence, France
Typology of green: Vertical green wall developed by Patrick Blanc
Designers: Patrick Blanc
Completion: 2008

Figure 85 The construction sequence of the bridge revitalization with the vertical green wall.
SOURCE: Patrick Blanc official website

[36] French botanist and the inventor of the Vertical Garden nominated (Mur Végétal). Since the first patent of the vertical green wall concept dates back to the years 1930 (USA Patent No. 159,789, 1937)

A project, worth to mention due to its enormous scale is the Paris Metro Refurbishment. It is under construction and the main team is composed by "Jardins de Babylone". This company is operative since 2004 providing solutions for architects' developers and various enterprises. Working in close collaboration with specialist metalworkers, engineers and joiners, the company is capable of proposing out-of-the-ordinary solutions such as the hanging garden and columns.

Project Name: Revegetation of Metro
Location: Paris, France
Typology of green: Green Wall Columns, green walls, gardens and terraces,
Designers: Amaury Gallon [37]
Completion: Future

This project is brought as example for implementation of this typology in great urban areas. Designed to create a plant architecture in harmony with the Parisian style of the place, the support structures of the plant elements are made-to-measure. The materials, whose estimated lifespan must be greater than 15 years, are chosen to adapt to the mineral environment and provide an organic touch that was previously lacking to users.

At the level of the support walls of the tracks, bins inspired by saprophytic mushrooms (found along the tree bark) will bring both organic touches and touches of greenery all along the route of the trail. user[32].

Figure 86 Bins inspired by the nature, (left) concept and realization (right)
SOURCE official website Amaury Gallon www.greenwallsdesign.com

[37] The creator of green design and green walls. "Driven by the need and the desire to create, Amaury Gallon embarks on the innovation of green walls. Thus, he develops a technique resulting from recycling and deposits the patent on the waterproofing of his green wall". www.greenwallsdesign.com/inside/green-designer-amaury-gallon/.

Building scale

Many realizations of green walls regard the building scale. They are used both for interior and exterior of the edifice. A project which has transformed the interior of an old fabric is worth to be mentioned. This venture changed an old fabric into a contemporary office for the headquarters of the company Green Fortune. It is located in Amsterdam and its characteristic design adds more diversity to the workplace within the space provided. It's a good example to be implemented in similar indoor environments since the climate inside is controlled. Bringing plants into an office has shown to improve employee productivity and boost general wellbeing, due to the natural affinity humans have with plants, known as 'biophilia'. Some projects of different caliber and typologies of this company are attached for further enhancement in attachment G_4.2.2.

Project Name: Green Fortune Epifyt Office
Location: Gedempt Hamerkanaal 111 1021 KP Amsterdam
Typology of green: Vertical green wall dimensions of 35 m^2
Designers: interiors by i29 and Green Fortune
Completion: 2016

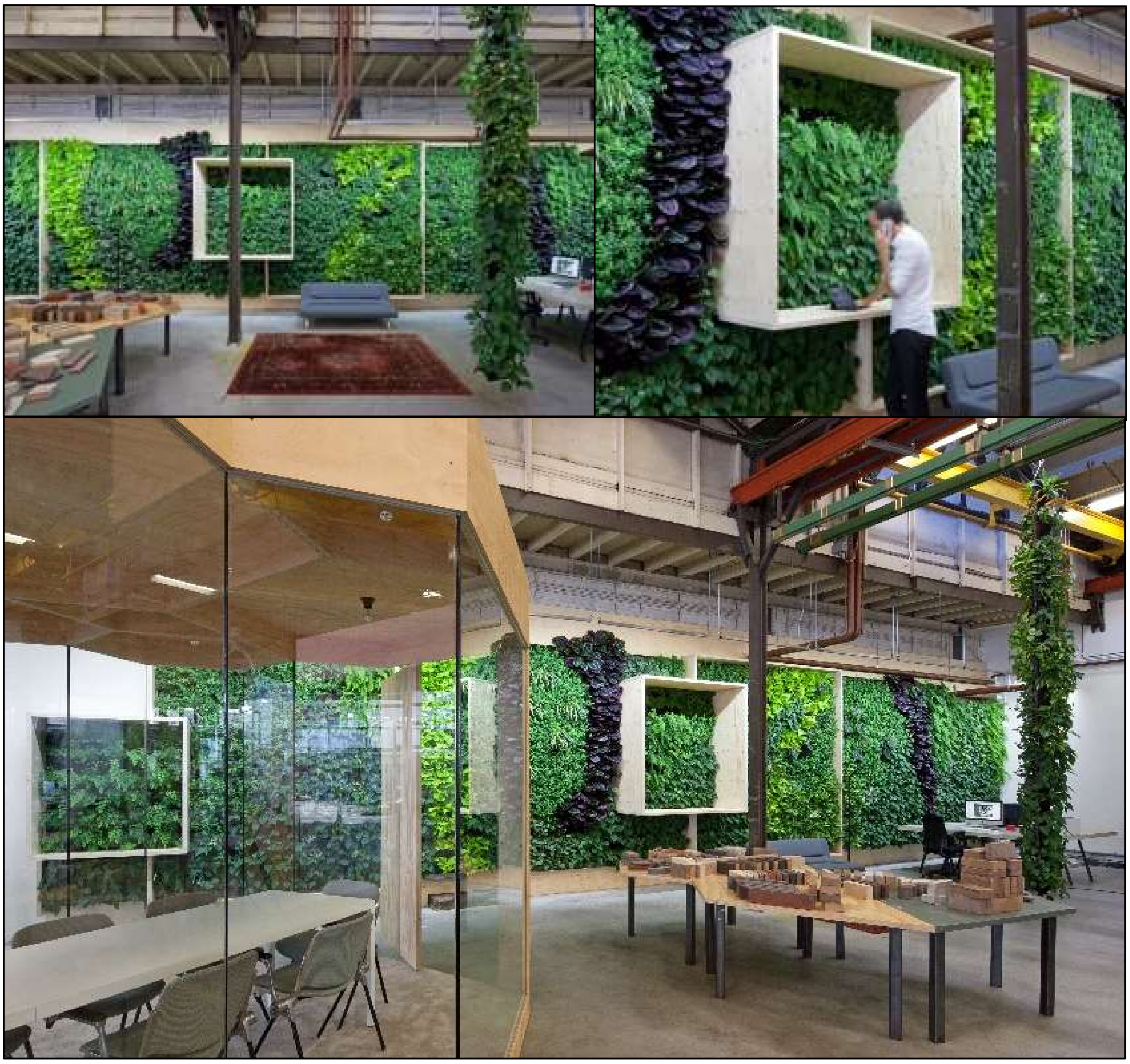


Figure 87 The interior workspace of the facility implementing greenery.
SOURCE: Greenfortune

This exterior wall design project is brought as an example of the flourishing biodiversity. Furthermore, its original design sheet is illustrated.

Project Name: Willmott Dixon Office
Location Southampton, United Kingdom
Typology of green: Exterior large-scale living wall with deciduous species 150 m^2
Designers: Biotecture living walls
Completion: 2015

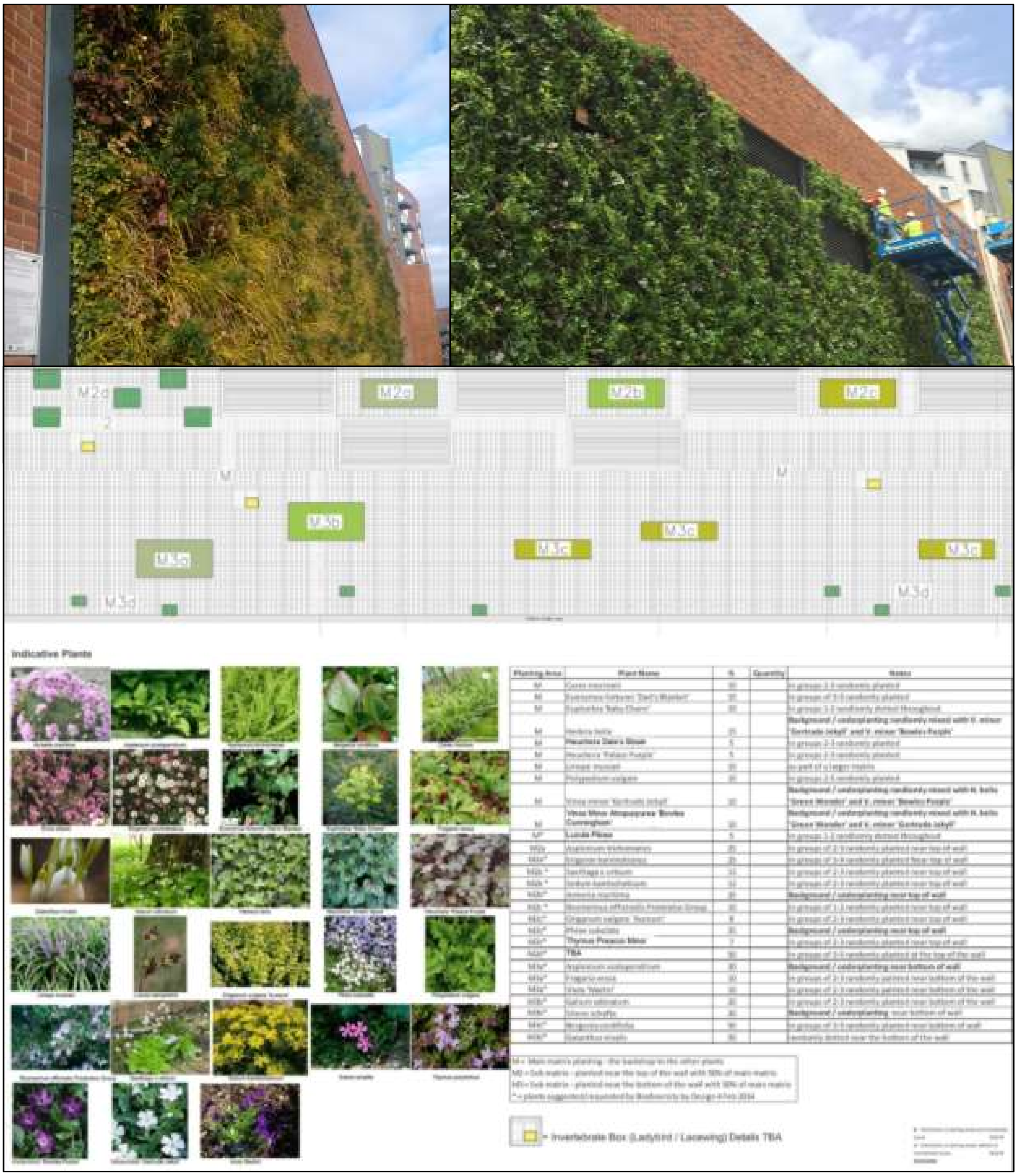
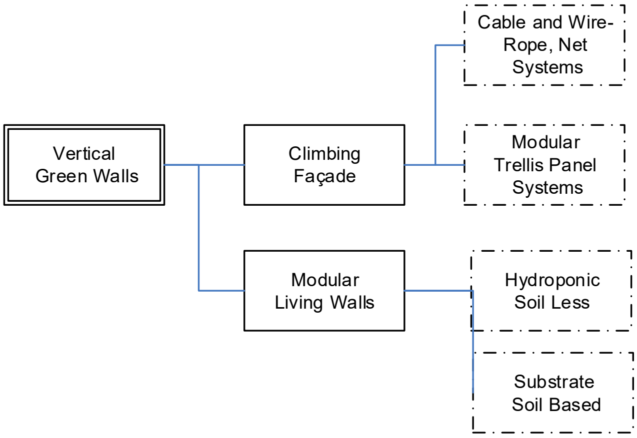


Figure 88 Design of the above vertical wall. All the species are coded and located in the specific places. SOURCE: Biotecture Living Walls

4.2. Living walls and technological solutions for vertical green

This chapter describes the different types of vertical green solutions and makes a comparison in the end. First, a preliminary selection of worldwide producers is made. This selection is made considering the successfully completed projects and the variety of solutions offered by the company. Then the major characteristics of each typology are stated technically. In the end a list of physical benefits is illustrated, together with the critics. To complete the study and show the feasibility in this context an attachment A1_4.2.3. shows a map of the living wall existing constructions in the Turin city in San Salvario and Crocetta area. Three typologies of these construction in the zone are analyzed and a thesis project of the zone is given as an example of living walls design.



SCHEME 6 The four branches of VGW subject to further analysis and comparison for their implementation in final design

4.2.1. Climbing Façade

Modular Trellis Panel Systems

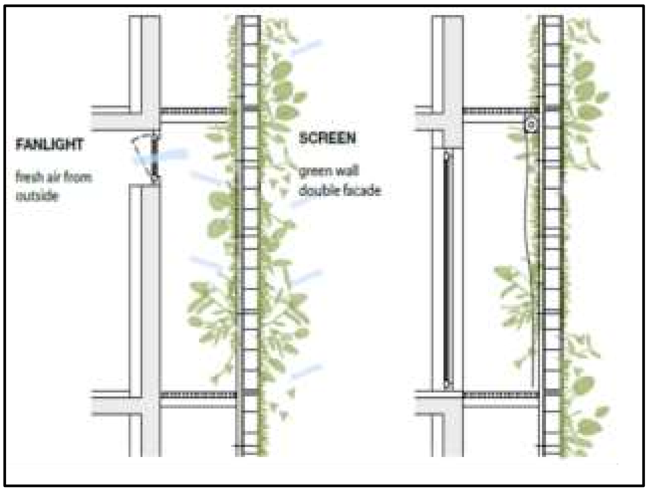


Figure 89 Example of a green wall installed with modular panels to make a duble façade SOURCE: [33]

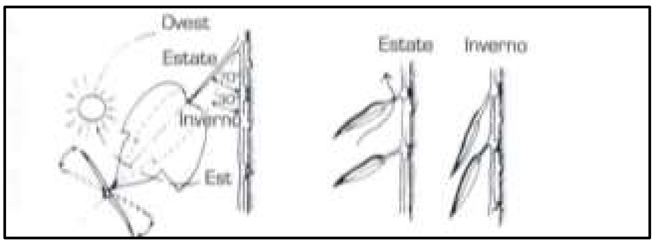


Figure 90 Orientation depends on the season and sun SOURCE:ANTONIO VOTTARI

This type of green wall is integrated to the existing wall and provides the necessary shading for the internal ambients besides allowing the ventilation. [33]The panels are rigid and fixed to the wall considering the type of plant that is being grown. The type of plant determines the module of the climbing façade and the openings.

Modular Panels are used for freestanding fences, covering walls, screens and enclosures. Plants also can hang down the modular trellis, at every level of building. They have diverse performances and specifications depending on the project. In specific periods of the year, depending on sun and climate the leaves orientate differently as illustrated in the figure on the left. [9]

The first productor famous worldwide for the construction of different green solutions is the greenscreen ®. They produce a wide range of technical solutions which are summed up below as follows.

A Wall Mounted Green Facade Trellis Panel

The elements are simple, and the possibilities are endless for mounting modular or shaped panels near entries, around windows and in interior courtyards as a living plant matrix that covers all or part of a building façade. Integrate wall mounted greenscreen elements into new construction or retrofit to existing buildings with adjustable clips that adapt to uneven surfaces. Panels can be stacked side to side or top to bottom to cover larger areas. The specific design does not allow the buildings to interact with the wall, this way not altering its physical properties.

B Freestanding Green Facade Wall.

This type of system provides the support for plants growing in vertical façades, its features make it desirable for use: "Light in weight, but incredibly strong, greenscreen's three inch screen depth "captures" plant material and provides the benefits of a living fence or tapestry that can be enjoyed from both sides"[34]. Furthermore, it has characteristics like adaptability that can be implemented in a wide range of projects. The mounting accessories match the panel finish and easily adapt to posts for simple fence installations or to more complex frameworks for larger multi-story projects. Working with the modular grid simplifies the design process and ensures accurate field installation.

C Column Trellis

Creating column shapes with greenscreen trellis panels is easy. The company provides a standard Column Trellis which is fabricated from a **112**cm wide panel which gives a **39.4**cm diameter column as the basic building element. The company provides mounting clips or brackets for attaching to the structure and you can choose from the standard radius up to **427**cm in height or select a custom radius or square column shape that can be preferentially build. For taller installations, the columns can be stacked. The standard Column Trellis can also be mounted on a fiberglass planter for applications that require self-contained units.

Figure 91 The diversity of the plants that can be used in trellis systems according to location and climate.

This systems can have many positive features, but if they are not well maintained, the results can be appalling and the time spent on the design process is considered wasted. The same Patrick Blanc is aware of this phenomena. He states that common mistakes in green walls include choosing the wrong species of plants or having too few varieties, which leaves the wall vulnerable. "Even if the right species were picked, many owners of green walls do not know how to care for them, which leads to the plants dying."[38]

Figure 92 The deterioration of the green systems due to the lack of maintenance and/or other factors
SOURCE: Perini TUD [23]

Table 16 Modular Trellis Panel Systems integration with the green list of BP benefits health benefits and critics

Modular Trellis Panel Systems		
Building Physics Benefits	**Health Benefits**	**Critics**
Shading in Summer	Sociological (meetings)	Periodical maintenance
Filter light in winter	Psychological (beautiful)	Lightning problems
Minimize Cooling	Physiological (low t°)	Dynamics
Increase Evapotranspiration		
Mitigate Urban Heat Island Effect		
Solar Radiation absorption		

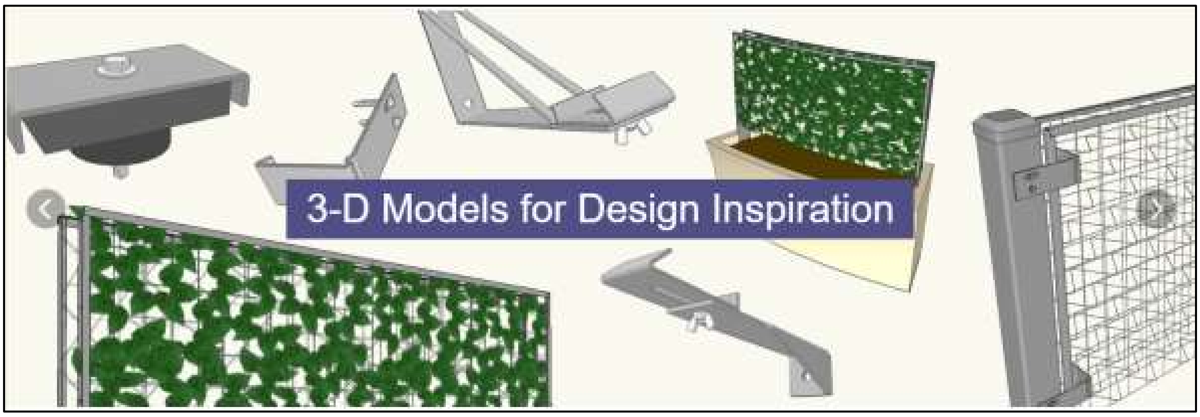
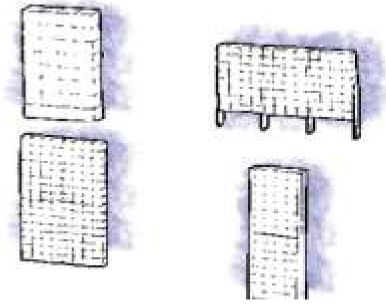


Figure 93 Possibility to implement directly the solutions in 3D modelling programs
SOURCE: greenscreen

[38] Patrick Blanc interview

Table 17 The positive features of Modular Panels and Columns for LWS
SOURCE: Greenscreen

Positive Features of Modular Panels	
TECHNICALLY	
Simple	
Modular grid/Adaptable in dimensions	
Light in weight	
Structurally robust	
Interior use also	
In-altering the existing wall properties	
	 Memorial Hospital, Houston, TX
 Premier Auto - Irvine, CA	

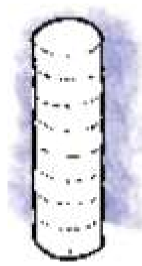
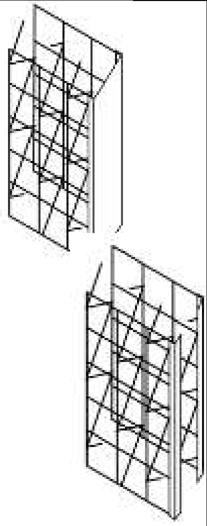
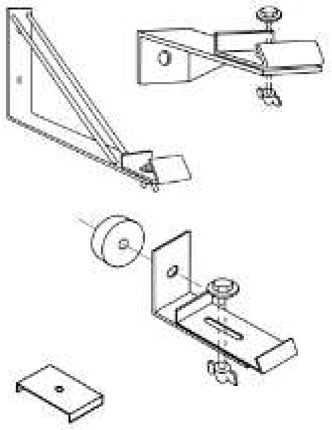
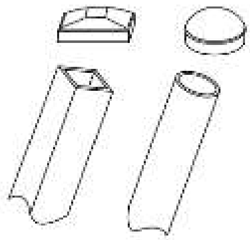
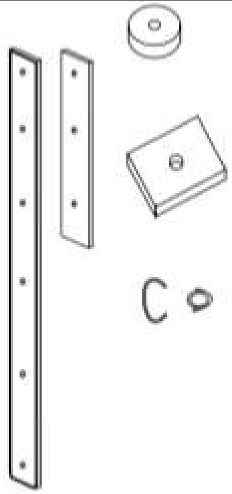
Positive Features of Columns	
TECHNICALLY	
Simple	
Standard size	
Preferred size	
Structurally robust	
Stacking Possibilities	
Fiber glass use for self-containing	

Table 18 Detailed technical components of a LWS and an illustration of fixture element SOURCE:Greenscreen

TECHNICAL DETAILS			
EDGE TRIMS	**MOUNTING CLIPS**	**POSTS AND CAPS**	**STRAPS RINGS SPACER**
			

Cable and wire-rope net mesh.

This is another type of climbing façade which consists of two different systems. They can be used individually or together. There is a distinction between them. Cables on green facades are designed to support faster growth of the climbing plants that have a denser and thicker foliage. Wire rope nets are frequently used to support slower growing plants. This system is rather flexible and possesses a better degree of design applications than cables. Technologically they function in the same way. Both systems use high tensile steel cables, anchors and supplementary equipment.[35]


Figure 94 (left) Cable system (right) wire-rope net system
SOURCE: greencabler left, wire-ropemesh right

Figure 95 A detail of the option for fixing the cable
SOURCE: greencabler

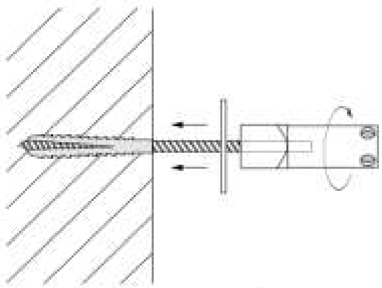
There are various ways of fixing a cable system. On the left is represented one of them. "The trellis structure is comprised of a cylindrical base with four drill holes through which the cable is inserted. This permits easy assembly and provides high design flexibility".[36]

Two tables in the following pages show the benefits of using these systems and some technical specifications for the installation sequence and the flexibility of their components.

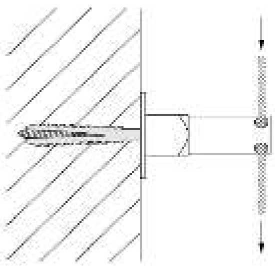
Table 19 The cable system features and installation process
SOURCE:Begrünungssystem

Cable system	**Features**
	Easy assembly
	Robust
	Corrosion-resistant
	Flexible design
	Modular concept
	Harmonious surface – anodized silver

Installation Process

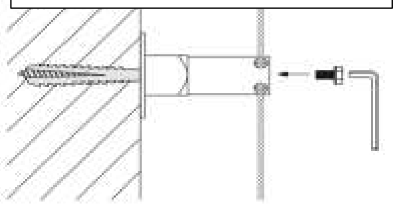


Step 1 drilling



Step 2 cable insertion

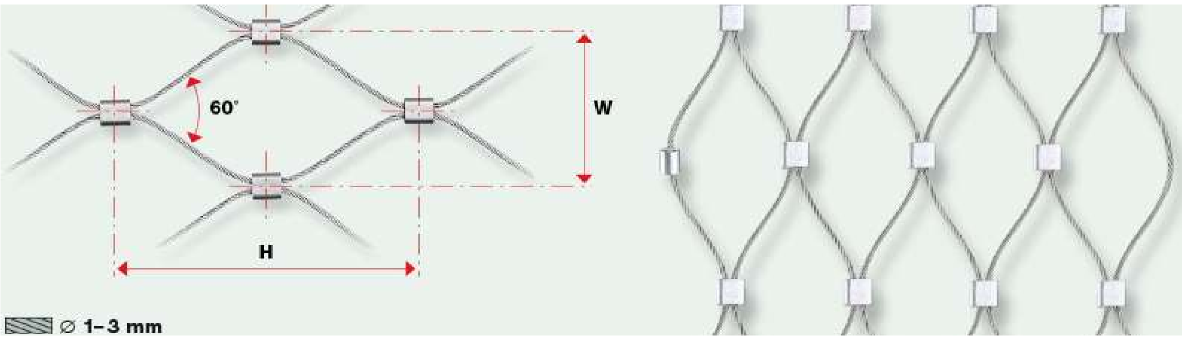
Step 3 fixing permanently



[37]

Table 20 The principal features of the wire rope net system and dimensional characteristics
SOURCE: webnet

Wire rope net system	Features
	Pre-assembled mesh Robust Corrosion-resistant Flexible design Modular concept Ideal for perimeter design
Flexibility of dimensions	



[38]

4.2.2. Modular Living Walls

This type of living wall differs from the climbing façade in many aspects but the fundamental one is that they have roots for their nutrition in a special support and not in the ground. Living walls are self-sufficient vertical gardens that are attached to a free-standing frame or to the exterior or interior of a building. There are two ways of growing the modular living walls. Soil based substrate is the traditional way, while the hydroponic growth is a more advanced technique that does not use soil to supply the necessary nutrients for the plant. These solutions are examined and compared in the end. [39]

From a functional viewpoint in a comparison to green façade most of these systems need more complex design, as a greater number of variables must be considered, like: involvement of several layers, attention on the mechanism of water and nutrient, supporting materials. [40]

Hydroponic living walls

In a horizontal landscape, the water transfers nutrients necessary for the plant growth. This process is hard to be done in vertical walls, since its contrary to the physics of most of the plants. A good solution is to search for plants which adapt better to this position and the other one is to use a special compost. In this section the hydroponic solution will be analyzed. The source to make the analysis is a certified producer from Great Britain which offers a variety of solutions and has already demonstrated in several projects the efficacity of this system. Why using hydroponic instead of normal soil? A summary of the reasons is represented in the table below:

Table 21 Hydroponic vs soil table of comparison

HYDROPONIC	SOIL
Food delivered directly to plant	60% of energy spent for food search
Zero-cation exchange	More water is needed for the irrigation
Nutrients are supplied in a precise manner	Limited variety of plants
Dimensionally Stable	Less divesity
Chemically Inert	
Supremely Water Efficient	
Withstand wind	
More predictable root zone	
Grow longer-lasting resilient plants	

Biotecture living walls

Biotecture is a company that produces hydroponic green walls. Its sustainable living walls are a flexible, modular system that helps transform any built environment. The patented hydroponic system brings a new level of sustainability through intelligent water management and stable system dynamics. The system is panel-based. It is extremely flexible to suit any size or shape installation. Plants are contained within discrete panels that contain an inert growing medium called Grodan. "The plants take root and anchor into the growing medium and each row of panels is irrigated and fertigated via precise pressure compensated dripline technology". [41]

The process of installation is simple and can be summed up in a few steps

- Agree panel layout, planting design and irrigation design.
- Plant panels on vertical nursery racks.
- First fix on site regards irrigation plant room, cladding & support structure
- Second fix on site regards panels' installation completion with semi-mature plants

Attention should be paid to the planting design phase. It is a delicate operation since it considers the site parameters (location, aspect, adjacent features). Furthermore, it considers native or near native plants and targeted plants for benefits (BREEAM, air pollution, IAQ, logo) and finally, the client preferences. Once is chosen the variety of the plants that will compose the wall, the nursery process begins and the steps above are followed sequentially.

They are proven in extremes of location, climate and contexts like: university campuses, high end retail outlets, restaurants and private gardens, as well as office buildings in Norway, private homes in Spain, and hotel landscaping in the UAE.[41]

Table 22 Hydroponic pros and cons table of comparison

Hydroponic systems	
Pros	**Cons**
Genuine, long-term sustainability	Requires a careful design
Resilience	Excessive costs
Ability to "pre-grow" the walls off-site	Two-step process
Faster installation times	The transportation may be harmful for plants
Instant visual impact	

Soil substrate living walls

This typology is not further examined since it has the same characteristics of the hydroponic walls, but with the only difference that instead of the hydroponic substrate, the plant takes its nutrients from the soil.

Costs of different greenery systems

Direct greening system (grown climbing plants): 30-45 €/m2

- b) Indirect greening system (grown climbing plants + supporting material): 40-75 €/m2
- c) Indirect greening system with planter boxes (LWS): zinc-coated steel (galvanized steel) 600-800 €/m2 coated steel 400-500 €/m2 HDPE 100-150 €/m2
- d) LWS based on planter boxes HDPE: 400-600 €/m2
- e) LWS based on foam substrate: 750-1200 €/m2
- f) LWS based on felt layers: 350-750 €/m2.

Data obtained from:[23] states that: Inside the range given, the costs depend on the façade surface (equipment) and height, location, connections, etc. The living wall systems are much more expensive than the direct and indirect greening systems, this is due to the maintenance needed (nutrients and watering system), the materials involved, the design complexity. This statement confirms the analyses and comparisons made in the previous chapters.

Finalised projects in the city

Name	Location	Year	Surface	Description
Relax space on green roof	Polytechnic of Turin campus, TURIN Cittadella Politecnica	2008	50 m^2	A covered living roof having as structure tensile cables and a mix of cable and wire-rope net system

Figure 97 The principal support structure.

Figure 96 The plants are grown in appropriate pots and follow the horizontal grid initially. They proceed horizontally forming a vegetal roof and finally ending close to the the boundary of the structure.

Figure 98 Columns serve as the element which supports the cable that is anchored in the ground.

Figure 99 The material of the mesh is not steel or aluminum as usual, but plastic for the roof mesh where the foliage grows.

<table>
<tr><th>Name</th><th>Location</th><th>Year</th><th>Surface</th><th>Description</th></tr>
<tr><td>Emergency scales Covered in green</td><td>Polytechnic of Turin campus, TURIN Cittadella Politecnica</td><td>2008</td><td>105 m² each scale</td><td>Three green covered emergency scales having as structure a modular trellis system</td></tr>
<tr><td colspan="2">The principal support structure are the emergency scales components.

</td><td colspan="3">They serve as the element which supports the modular trellis which grid is represented below.

The material of the mesh is steel.
This is a genial solution, because the green is added to an existing support structure and the only additional component is the trellis needed for the plants to climb. The type of plant used for the vegetative part is "Parthenocissus Quinquefolia"as it can be seen in the left part of the table.</td></tr>
</table>

Table 23 A sequence of four emergency scales covered in green at Polytechnic University of Turin. SOURCE: author

<table>
<tr><th>Name</th><th>Location</th><th>Year</th><th>Surface</th><th>Description</th></tr>
<tr><td>Freestanding fence inside the campus</td><td>Polytechnic of Turin campus, TURIN Cittadella Politecnica</td><td>2008?</td><td>200 m^2</td><td>A long freestanding fence inside the campus that follows the way from mixTo bar until the innovation hub.</td></tr>
<tr><td colspan="2">The principal support structure is the support wall of the road in the level above.</td><td colspan="3">They serve as the element which wires the modular fences whose grid is built in steel.</td></tr>
<tr><td colspan="2">
The plants hang down and cover the concrete support structure</td><td colspan="3">
The species are…</td></tr>
</table>

Table 24 Rappresentation of a module that composes the freestanding fence along the way from the canteen and mixTo bar till the innovation hub SOURCE: author

Local Design: Architectural language and technology of green wall systems in a Turin office building design.

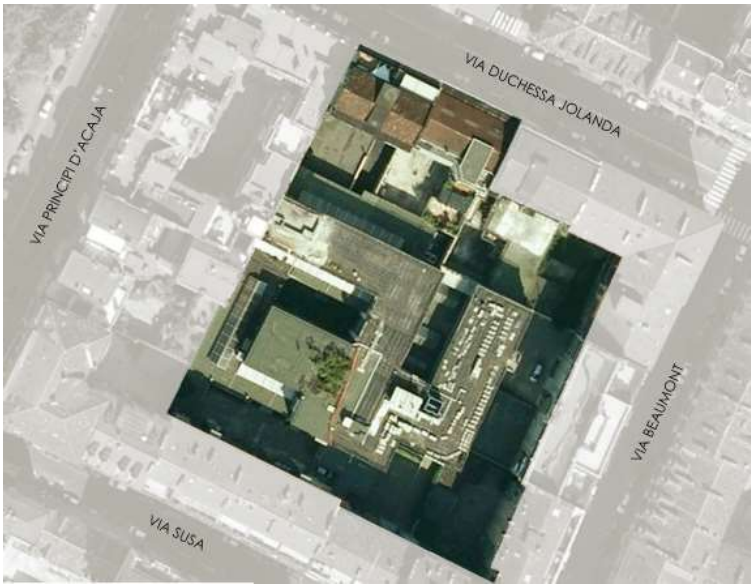


Figure 100 The location of the intervention SOURCE *[9]*

Figure 101 Context rappresentation of the final solution SOURCE: (VOTTARI, 2012)

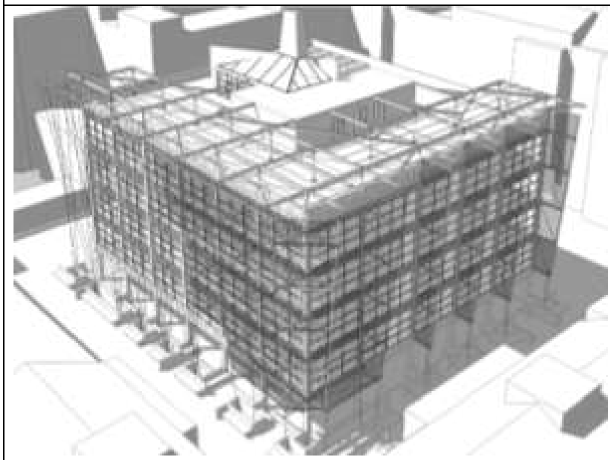
This master's thesis proposal, presents an intervention in an existing building in Turin. The target was to use the vegetal shading system for improving the energetical performance of the building. The focus was on compositional and technological aspects of this solution as well as the performance. [9]

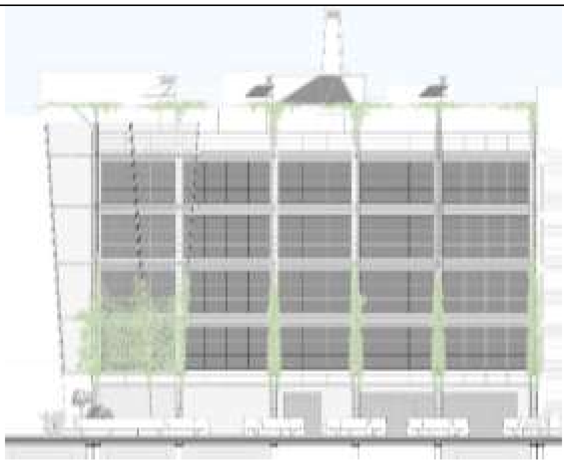
The vegetal shading system analyzed the control of the solar radiation and the final solution depended on the sun path in that orientation. Finding the right intervention proved to be challenging.

Situated in a dense urban area the problem for planting green areas consisted in the lack of space. So, the vertical surfaces were confirmed as the most suitable solution for this and the other multiple complications.

This green façade would bring a suitable solution for the lack of space, the phenomena of urban heat islands and a series of other positive benefits.

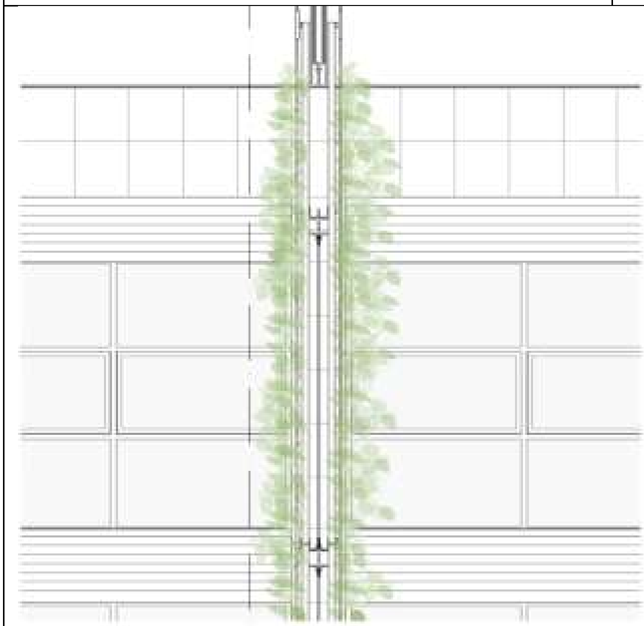
FINAL SOLUTION MODEL

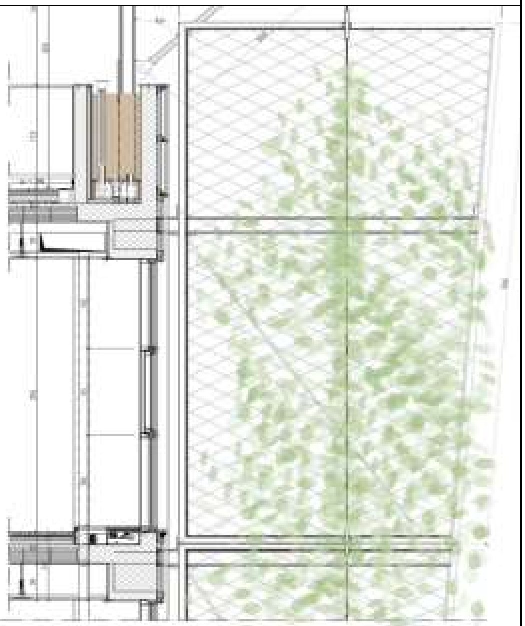




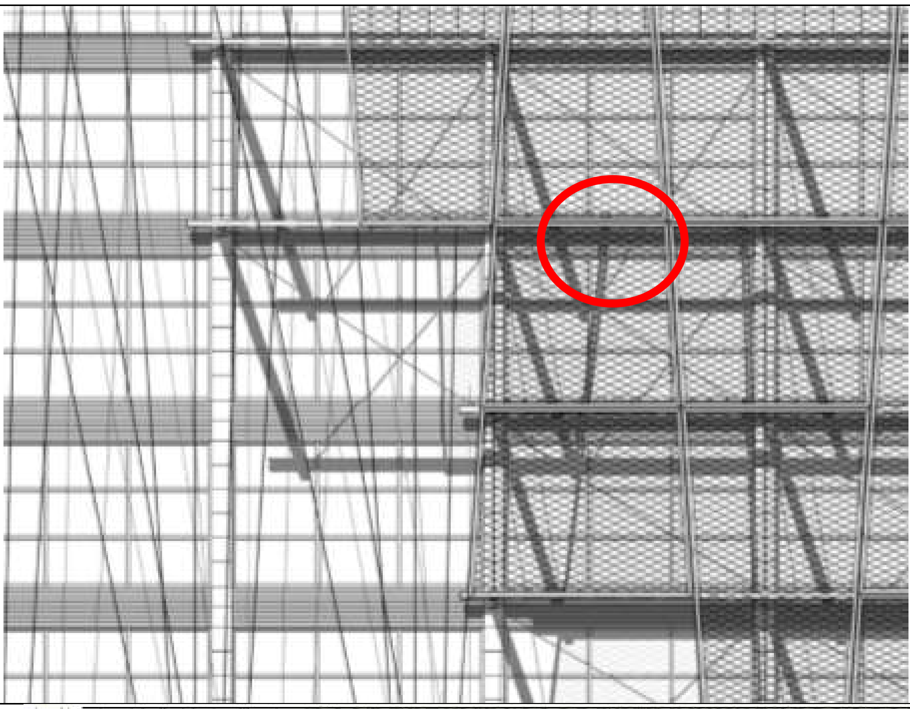
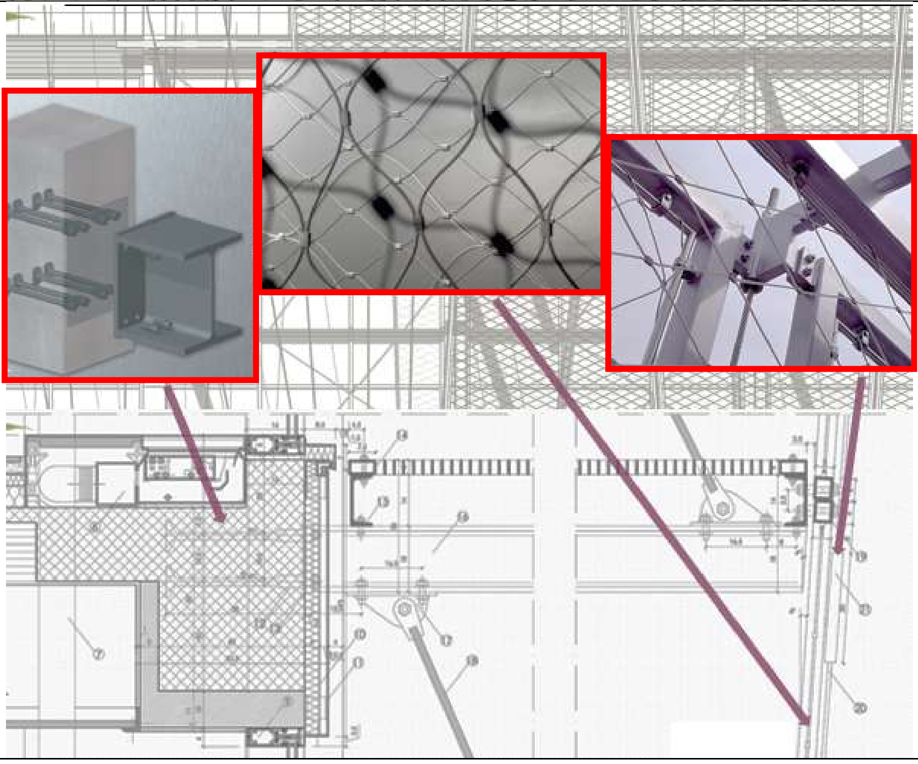
South East Front 62° w.r.t EW axis

South West Front 28° w.r.t EW axis





The model represented above shows initially the structure of the solution. The full vegetation is given in the second figure of the table where the building seems completely immersed in green. Then we can see two façades orientated in the most radiated axis South-(East-West). The structure that holds the greenery is composed of wire-rope net mesh as well as cables. As it is represented better in the following table of the technological aspects.

TECHNOLOGICAL ASPECTS



In this design there were proposed two different species for the façade. Each one of them has a specific growth and needs to be nested in a particular type of system. The first one is "wisteria sinensis" and uses the cable system to develop. While the second specie is the "Parthenocissus Quinquefolia" that can be grow only on wire-rope net mesh. In the table that follows is illustrated the plant type and some technical details in the way of nesting and anchoring.

VEGETAL SPECIES	
	
	
WAY OF ANCHORING	
CHANGEABLE	BINDING
TWINING PLANTS	LEAF - STEM CLIMBERS

The study is represented in a counter logical way, because the project example is given first and then is followed by the description of the typology of living façade. The next section zooms in the cable wire-rope net mesh system for the growing of the living facades.

4.2.3. Final comparative table

Table 25 Technical comparison and the likelihood scale of VGW aspects

VERTICAL GREEN WALLS	COMPARISON									
	Technical					Scale from 0-3 INCREASING				
	Simple	**Modular**	**Light**	**Robust**	**Corrosive**	**Water**	**Soil**	**Biodiversity**	**Space**	**Farming**
CABLE / WIRE-ROPE NET MESH	✓	✓	✓	✗	✗	**2**	**3**	**1**	**1**	**1**
MODULAR TRELLIS PANEL	✓	✓	✓	✓	✗	**2**	**3**	**1**	**1**	**1**
HYDROPONIC	✗	✓	✗	✓	✗	**2**	**0**	**3**	**2**	**2**
SUBSTRATE	✗	✓	✗	✓	✗	**3**	**2**	**2**	**3**	**3**

The likelihood scale is made based on the description in the paragraphs of the chapter, unfolding all the specifics of different systems.

Table 26 The benefits of the VGW taken as

VERTICAL GREEN WALLS	BENEFITS				
	Environmental				
	Cooling, Shading, Humidity	Reducing runoff	Improved Air Quality	Address Biophilia	Sound Barrier
	Economical				
	Less sewage	Reduced painting	**Energy savings**	Incentives	
	Social & Health				
	Playing Meeting Less Stress	Sports Recreation	Faster recovery patients		

5. Design process of innovative office building, a preliminary.

Implementing the living organisms in the final design allows the building to have a dynamic character. Usually the term dynamic component evokes the image of a very sophisticated product that has complicated functioning. This is not the case of the design proposal for this facility. Nature has reshaped her dynamic "components" and tested their utilization in millions of years, restyling their functions as it best suited the boundary conditions. Differently from the technological components, they are complex and not complicated, since their functions and requirements depend only on the sun energy, CO_2 and water basically. Perhaps the answer to the design problems we are facing today already exist in the nature, the only move to make is being good observers and researching deep into its world. The VGS have the potential to integrate with the existing components of the building and play an important role in the energetical performance as it is itemized in the previous chapter. Their implementation in the design process was considered in the optics of a biomimetic approach for the solution to the existing issues of heating, cooling, wellbeing, biodiversity, providing long-term benefits in many aspects. The engineering faces a challenge in quantifying these positive earnings, but many other sciences, for example psychology, have noted these aids and documented in important publications as stated in the chapter 4.1.1.

The design proposal is made taking in consideration the present thematic of biomimetic architecture in particular the LWS as technological components and natural heating and cooling strategies. The idea of having a dynamic building, which does not use the most technologically advanced invention, but the genius of nature is the backbone of this project. Instead of being us the masters of our facility, as it was thought according to a mechanistic way (the case study was designed to work on a 24h regime, running on oil, an obsolete solution judging the present thematic of Climate Change), we should learn from our nature and observe its gifts for thriving. The sun as a source for heating and lighting, is a crucial factor in the energetical point of focus, a free and unlimited resource that was carefully considered in the façade design. In the project of new envelopes, the sunlight and sun path influenced their typologies. Based on the orientation there are thought three different types of skins which serve as the major actors for the heat gains and losses in the facility. The next important gift from the living world is the natural ventilation. The facility is designed with a double skin, in order to allow the recirculation of air in the winter and summer periods and intermediate ones. The system thought, makes it store the energy in the wintertime, warming up the air between the two skins and release it in the summertime to prevent the overheating. The building is designed to be multifunctional and societal, given the belonging feeling that the employers have with it, can be said that the familiar atmosphere intended to be created is easily to be achieved. The caretakers are keen to have worked in a building that with the new design opens opportunities of inclusion for everyone. The purpose as office allowed the plan of a modern distribution with functions that in the years of design were not considered. An important value that was taken into consideration was the meaning of the building. It is closely connected to the context and for years has survived the radical changes of the nation. Keeping this in mind, the intervention maintained many of its original appearance, because it is an important symbol for the city.

5.1. Evolution of the façade design in time

As it happens with most of the designs, the first concepts changed and evolved in time in order to satisfy the requirements precisely. The principles of a sustainable design following a biomimetic approach were applied throughout all its stages as common denominator.

The first intervention which was inspired by a crystal glass.

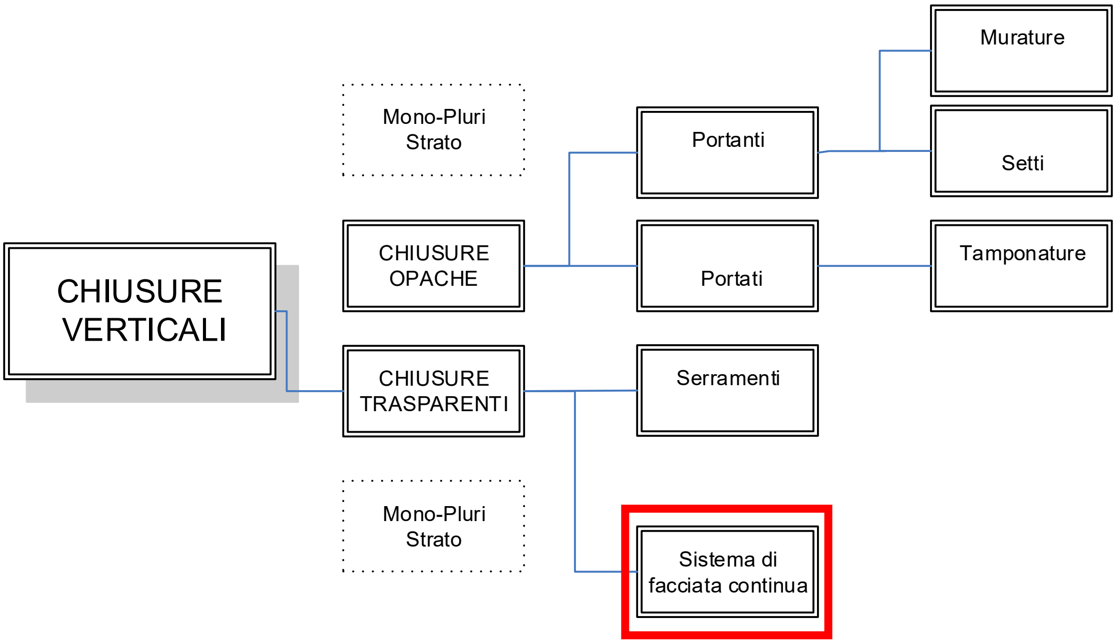
After the historical analysis, the value of the building proved to be inestimable. The anamnesis confirmed the firmness and the structural integrity of the complex. The problems consisted only on the asbestos presence and the scarcity of the envelope. The main idea that came out was to preserve it intact, like a crystal glass which conserves an important invention. The intervention consisted in introducing a transparent façade, that enclosed the building along its perimeter.

Figure 102 MVRDV's Glass Farm SOURCE: Persbureau van Eijndhoven

By doing this, the external appearance and conditions of the existing facility would have not changed in time. The thermo hygrometric conditions would maintain the setpoint values and the view would have been the exact same of a monument. Even though the inspiration was the main ingredient it did not go far, since the first renderings and professors' advices, pointed out the fact of the sun reflection on the transparent façade would hide the gem inside that big glass mass. Even though a particular type of glass, would have been used to make it less reflective to mitigate the suns effect, the problem of pollution and frequent maintenance would have risen the costs dramatically. Thus, it was opted for another solution. The proposals were many and the design evolved from week to week in the final one which is illustrated in the next chapter.

5.2. Intervention characteristics of the final façade design

The façade is the most characteristic part of the skyscraper and it is a typology of the vertical closure's family. The retrofit proposal of RAI skyscraper takes into consideration the key role that it plays in the energy saving. As determined from the studies of the thermal loads in the chapter 3. It is possible to save up to in the winter regime and summer regime.



SCHEME 7 The vertical closure hierarchy. SOURCE: UNI 8290

Generalities of the three types of façades as final design.

In order to conserve the monumental value of the building, the façade that faces the Cernaia Avenue oriented in the North East side of the complex is left intact and an intervention proposes an internal glass façade the inside the building It is represented in the green color, in the figure below. The only proposed idea of intervention in the existent façade is the integration of PV cells in the glass facing the XVIII Dicembre Square, without altering significantly the sunlight diffusion in the internal ambient. The same technology is applied also in this location, where the presence of the skyscraper is immensely felt, being the largest surface area. The internal façade continues also in the face of the internal courtyard delimited with the presence of scales, that serves as a physical separator and initiator for the other façade located in the opposite side of the scale in South-east.

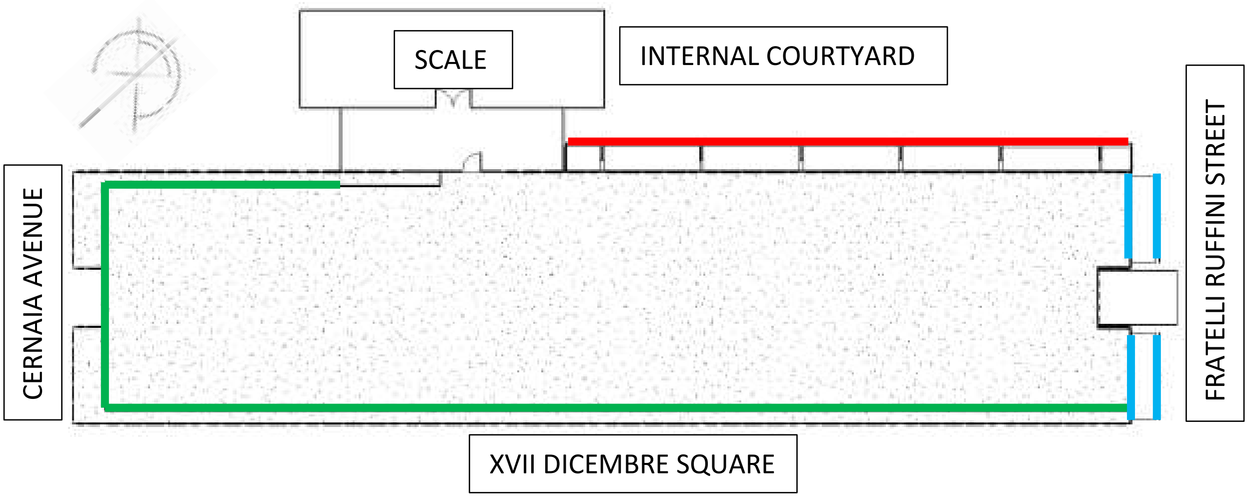


Figure 103 The three different façade interventions.

The part which was subject to a full intervention, is located in the South-east represented in red in the figure above. Its main components are modular and the VGS are implemented to mitigate the late morning sun principally, together with the other benefits that accompany the Living Walls as described before in 4.1.1. This area is designed to be as a refreshing area for the occupants and to allow the filter between the internal building and the external part of the surroundings. The main constrains are represented by the existing constructions in the internal courtyard, so the intervention starts uniformly from the third floor.

In the South-west of the skyscraper there is an existing emergency scale, which has its own modular trellis system that encloses it. Since the structure is already placed, it is ideal for planting climbing plants. The process of growing can be accelerated by adding pots every three floors so that the green has less distance to cover. In addition to this quick, but significant change, is planned a substitution of the existing façade windows and with more performant ones, making an intervention also in the structure. The structural intervention has as objective the elimination of the thermal bridges, by insulating well the node of the window and floor connection. The other element with natural origin is the wood which serves as a barrier to the sun, which according to the studies and historical events is the main generator of the cooling loads in summer, but also in certain days in the winter.

The details of the three façade typologies.

Figure 104 Facade Fratelli Ruffini

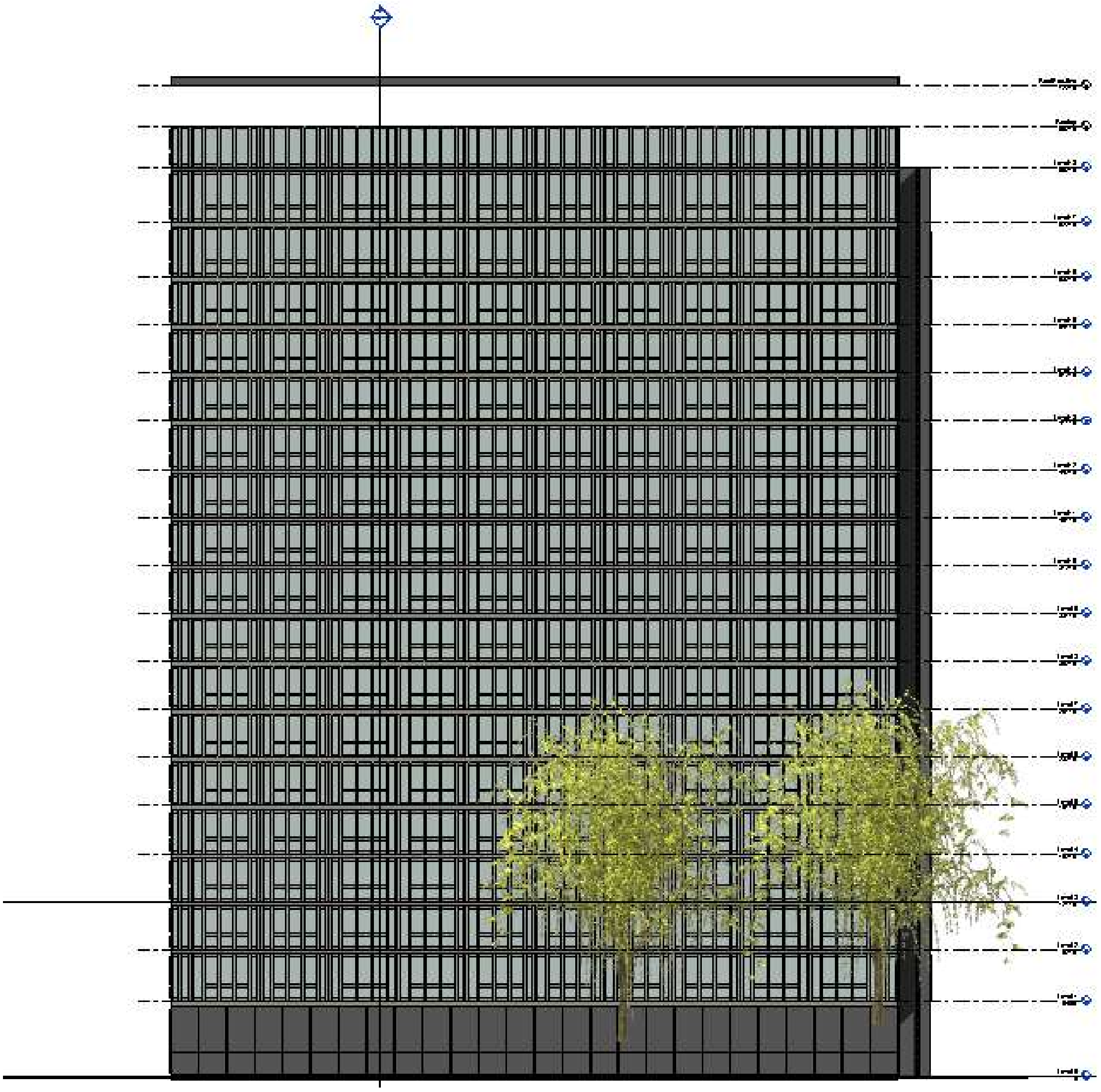


Figure 105 Facade XVIII Dicembre

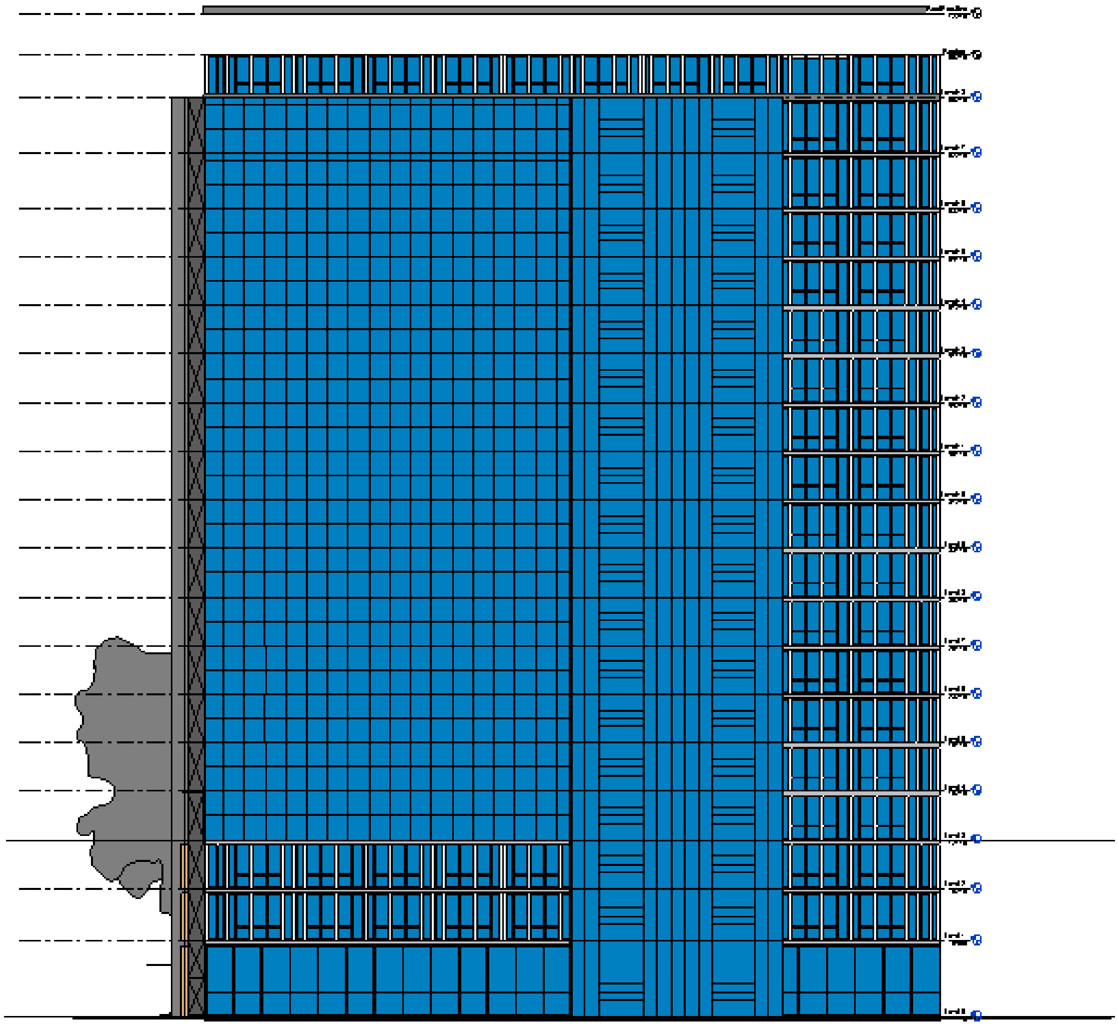


Figure 106 Façade via guicciardini

The connection details are given in the attachment.

6. Results and Conclusion

From the analysis made, the most suitable intervention for this facility, in order to preserve the original aspect and monumental values, a double façade is proposed from the inside. The role of the natural components is still a challenge to be quantified, but its positive effects are proven to be influencing the productivity and wellbeing of the occupants. The office in modern days is seen as a place that offers more than a desk and a chair, but also a pleasant environment and a more open visual. The energetical efficiency is dramatically improved placing the building in an accepted level according to the Italian legislation. The building materials are chosen to have a long life and are modular and recyclable at almost 100%. The cost of intervention is to be seen in a long-term return and the BEP should be further analyzed in another study that is not part of this thesis.

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Attachments

The list of the attachments is organized with a logic that regards the chapters for example: **A11_3.1.1. C_3.2.1.**

The first letter **A** stands for Attachment, the number immediately **11** after shows the sequence and three numbers **3.1.1**. that conclude represent the section of the chapter. The first letter of the second example **C** stands for calculations and the logic then is identical as the previous one.

Abbreviations

Abbreviation	**Description**
ABBR	Giovanni Astegno, Mario Bianco, Nello Renacco, Aldo Rizotti.
	Design team of the proposed regulatory plan in early sixties
approx.	approximately
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
BREEAM	Building Research EstablishmentEnvironmental Assessment Method
C.C.	Comunal Council
Com	Company
D.Mor.	Domenico Morelli
D.T.	Design Table
DISEG	Dipartamento di Ingegneria Strutturale Edile e Geotecnica
DISET	Dipartimento di Ingegneria dei Sistemi Edilizi e Territoriali
EPA	Environmental Protection Agency
G	Government
HF	Heat Flux
HVAC	Heating Cooling Air Conditioning
IAQ	Indoor Air Quality
ISO	International Standard Organization
IUPS	Implementation of Urban Planning Standards
LEED	Leadership in Energy and Environmental Design
LWS	Living Wall Systems
NZEB	Nearly Zero Energy Building
P.D.	Preliminary Design
P.W.	Public Works
PEEP	Piani di zona per l'Edilizia Economica Popolare
PRGC	Piano Regolatore Generale Comunale
Quot. L.S.	Quotidiano La Stampa
RAI	Radio Televisione Italiana
RTM	Regional Technical Map
TE	Tertiary
UAE	United Arab Emirates
UHI	Urban Heat Islands
UNI EN	Ente Nazionale Italiano di Unificazione
USGBC	United States Green Building Council
ZEB	Zero Energy Building

Table of figures

Figures

Tables

Schemes