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Engineering

Master of Science – Building Engineering



**BIM and BEM Interoperability–Retrofitting Strategies
for a Historic Case Study in Borgo Pirelli**

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Abstract

The construction industry's need to digitize existing heritage buildings for effective management during their operating phase can be addressed by 3D laser scanning surveying techniques.

The 3D laser scanner surveying technique captures and represents geometric information in the form of three-dimensional point clouds. This tool accelerates the digital modeling process while ensuring accurate and realistic geometry representation. This surveying technique, when combined with Building Information Modeling (BIM), can efficiently create precise BIM models for energy analysis and evaluation of existing heritage buildings. The Borgo Pirelli housing complex in Milan serves as a case study,

The aim of this study is to demonstrate the potential of 3D laser scanning surveying techniques in combination with BIM modeling of existing buildings. This was achieved by digitizing the existing assets and creating accurate BIM models, which allowed for HBIM modeling and energy analyses. The study also sheds light on the present challenges related to the interoperability of Revit and IESVE software during the BIM to BEM transformation process by using the BIM model exported in gml format. Furthermore, the study suggests potential renovation strategies for historic building interventions.

Introduction

Buildings are responsible for approximately 40 % of energy demand in the European Union (EU), In addition, the building sector is an important contributor to global warming by releasing 40% of all greenhouse gases (International Energy Agency, 2013). In recent years, both global building energy utilization and global carbon dioxide (CO₂) emissions related to the building sector have increased by 1% annually necessitating the implementation of various policies worldwide to address this problem, such as the Energy Performance of Buildings Directive and the International Annex 56 project, both of which aim to provide cost-effective solutions for energy-efficient building renovation. Renovation projects may also implement building environmental assessment schemes, with energy retrofitting encompassing physical or operational modifications that reduce energy consumption and improve building energy performance.

Building Information Modeling (BIM) plays a vital role in this industry by providing a comprehensive virtual model of a building, enabling the simulation of a building's energy performance, and identifying areas where energy efficiency can be improved. The combination of BIM with energy-efficient building renovation policies enables design and construction teams to optimize a building's energy performance, assess the impact of various retrofitting options, and collaborate more efficiently, resulting in cost savings, reduced risk of errors and delays, and the fulfillment of the growing demand for sustainable and energy-efficient buildings.

Milan has undergone a recent surge in architectural and energy redevelopment within its urban context, The Borgo Pirelli housing complex, erected more than a century ago by the Pirelli company for its employees. The goal of the redevelopment effort is to enhance the quality of the housing and increase energy efficiency, transforming it into a model for not only the Milan community but also similar areas.

Historical Building Information Modeling (HBIM) offers a solution for the three-dimensional modeling of historic real estate assets, managing their entire life cycle and providing information related to energy parameters, performance, degradation, and cost. The approach uses a "reverse engineering" process to recreate a digital simulation of the design with the highest possible accuracy.

The energy optimization of a cultural heritage site villa was achieved by using 3D laser scanning to collect geometric data, which was then used to create a HBIM model. The HBIM model was transformed into a BEM model using the EAM model, and various engines were used to recommend energy-saving interventions suitable for historic buildings. IESVE software was utilized for energy analysis and to ensure compatibility with Revit software programs. The retrofitting strategies included adding insulation to the roof and walls and enhancing the window configuration. The analysis resulted in an optimal outcome selection for reducing energy consumption.

Chapter 1 - HBIM Modeling for Digital Restitution and Case Study Presentation of Borgo Pirelli

1.1 The Importance of Energy Efficiency in Historical Buildings: Preserving the Past while Building a Sustainable Future

Energy efficiency in historical buildings refers to the use of various techniques and technologies to reduce the energy consumption of a building while preserving its historical and cultural significance. This can include measures such as improving insulation, upgrading heating and cooling systems, installing energy-efficient lighting, and using renewable energy sources, among others. The objective is to decrease the energy consumption needed to operate the building, while preserving its historical and architectural integrity, which can be beneficial in the long term with respect to:

Environmental sustainability: Historical buildings are often energy-intensive due to their outdated construction methods and lack of modern technology. This can result in a significant amount of energy waste, which contributes to greenhouse gas emissions and climate change. By making historical buildings more energy-efficient, we can reduce their environmental impact and help to create a more sustainable future.

Economic benefits: Improving the energy efficiency of historical buildings can lead to significant cost savings over time, as energy bills will be lower. This is particularly important for buildings that are used by businesses or organizations, as they can redirect the money saved on energy towards other areas of their operation.

Preservation of cultural heritage: Historical buildings are an important part of our cultural heritage and are often protected by law. By making these buildings more energy-efficient, we can ensure their longevity and continued use, while also preserving their historical and architectural significance for future generations to enjoy.

Health benefits: Many historical buildings were constructed using materials that can be hazardous to human health, such as lead and asbestos. Improving the energy efficiency of these buildings can often involve replacing these hazardous materials with safer alternatives, which can lead to improved indoor air quality and a healthier environment for occupants.

1.2 Building Information Modeling

BIM, or Building Information Modeling, is a powerful tool in the construction industry that involves creating and managing digital models of physical and functional characteristics of a building or infrastructure project. BIM models provide information about both the physical components of a building, such as walls, floors, and mechanical systems, as well as the functional aspects, such as lighting and energy performance. BIM software programs enable users to create detailed 3D models of buildings and simulate the performance of building systems under various scenarios.

The modeling process of BIM involves creating a simplified digital virtualization or simulation of reality in the construction world through data or information that can be reinterpreted and reworked by software independently. Its purpose is to represent, approximate, and simplify all real information, not just limit itself to three-dimensionally representing the building's geometry. The main goal of BIM is to create a digital representation of a building or building system that is integrated with its main physical and functional characteristics, allowing architects, engineers, and construction professionals to design, construct, and manage buildings more efficiently.

1.3 BIM for existing buildings

Historical Building Information Modeling (HBIM) is a specific approach to building information modeling (BIM) that is designed for modeling and managing historic buildings and structures. While BIM is mainly used for managing the construction process of new buildings, HBIM offers a possible solution for the 3D modeling of historical real estate heritage, managing the entire life cycle of buildings, focusing on their use and valorization. In Italy, for instance, around 60% of historic and residential buildings have exceeded their useful life, which calls for the need to evaluate existing building recovery through energy redevelopment or restoration.

HBIM extends the capabilities of traditional BIM by incorporating reverse engineering processes that investigate the procedures and processes that led to the construction of the building or structure. This enables the modeling of existing buildings by acquiring as much information as possible to recreate a digital simulation of the building. Reverse engineering is used to analyze every component and achieve maximum model accuracy

in line with the purpose of the modeling, focusing on relevant aspects of design and construction to achieve the desired outcome.

The main goal of HBIM is to create 3D digital models of existing historic buildings that can manage all the main information and data related to the building, including geometric data, energy performance, degradation, costs, and maintenance. HBIM can significantly enhance the potential of BIM by extending its use beyond new buildings to create intelligent models containing data and information from existing structures, where all digital model components are parametric objects with a well-defined semantics. The HBIM approach is particularly useful for assessing existing buildings for energy purposes, where detailed information on spaces, technological aspects, and systems is needed.

1.3.1 3D surveying

HBIM modeling requires a survey on-site, which can be done using traditional surveying methods or innovative surveying techniques, such as laser scanners. Laser scanning is the most accurate and widely used method for conducting a 3D survey, which generates a point cloud as a starting point for modeling. The point cloud consists of referenced points that allow for the extraction of geometric and colorimetric information. Laser scanning enables the collection and management of the entire survey in a single file, providing a precise, detailed, and easily manipulable digital representation. This methodology significantly reduces time compared to traditional surveying methods, as it requires positioning the scanning tool following a continuous ring of visible stations to obtain a high level of detail and precision.

1.3.2 Laser Scanner

The laser scanning method uses a laser scanner-equipped instrument to create a map of a building by utilizing electromagnetic signals in the form of laser light. In the detection phase, the distance of a point is measured by calculating the time interval required for the laser to reach the survey target and reflect to the emission point. A major difference between a laser scanner and a conventional topographic instrument is the instrument's execution speed and capacity to store data. The laser scanner measures horizontal and vertical angles, as well as the distances of specific points, thousands of times per second. This technique enables the collection of coordinates for many points on the scanned surfaces, which results in a point cloud.



FIGURE 1 - EXAMPLE OF A LASER SCANNER TOOL - TRIMBLE TX8 3D LASER SCANNER

(PRE-OWNED TRIMBLE TX8 3D LASER SCANNER | AGS (AGSGPS.COM))

This technique allows for rapid surveys using simple technology. The instruments are equipped with integrated software provided by the manufacturer, which guides the operator through the scanning process with simple steps. The only constraint that must be respected for the use of this technique is related to weather conditions: in case of rain, it is not possible to use the scanning instrument, as a laser beam intercepting a water drop interferes with the measurement and compromises the entire survey.

Today, there are three main types of laser scanners that can be used to carry out a three-dimensional survey: time-of-flight technology, phase difference, and triangulation.

The time-of-flight scanner calculates the time taken by the light beam to cover the distance between the instrument and the survey surface, knowing the speed of propagation of the light beam.

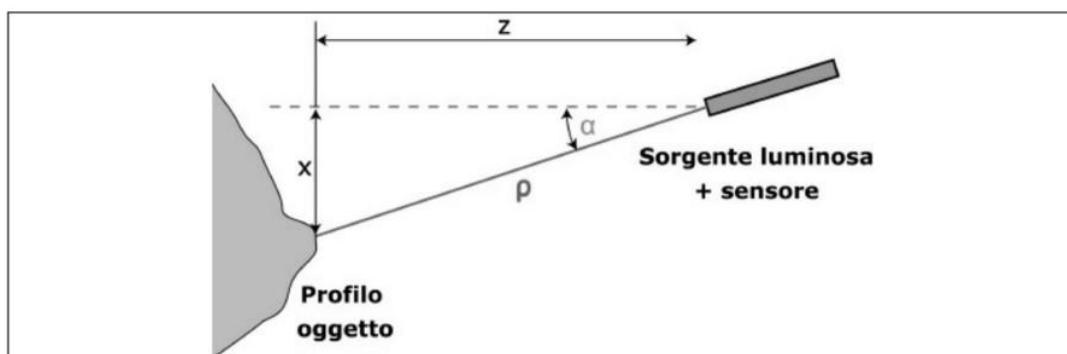


FIGURE 2 - OPERATING PRINCIPAL DIAGRAM - TIME-OF-FLIGHT (TOF) SCANNER - RUSSO, REMONDINO, GUIDI.

The phase-difference scanner calculates the distance of the points by evaluating the phase difference between the transmitted and received waves.

The triangulation scanner measures the distance by using an infrared sensor that captures a pattern of points on the surface being surveyed.

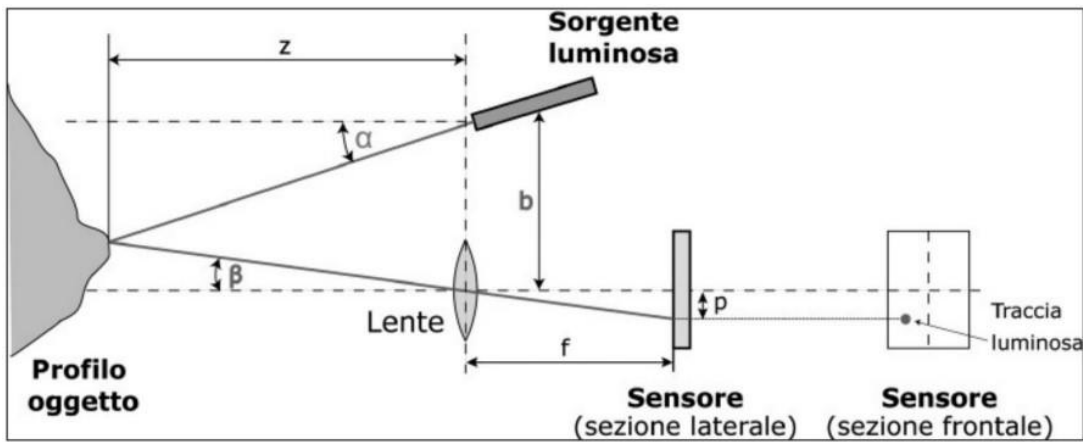


FIGURE 3 - PRINCIPLE OF A 3D SCANNER USING TRIANGULATION WITH EMISSION OF A SINGLE LASER LIGHT SPOT - RUSSO, REMONDINO, GUIDI.

The latest surveying tools come equipped with cameras that can identify the varying shades of color in each point obtained during the survey. This capability allows for the creation of orthophotos and the planning of restoration work on existing historical sites using the point cloud as a foundation. However, optimizing the survey process to generate a precise model requires several key considerations. These include ensuring that the instrument's visibility is not hindered by obstructions on the site, guaranteeing that all points of the building are visible from all survey stations, analyzing shadow zones beforehand, and conducting measurements during optimal weather conditions to avoid interference with the laser beam caused by direct sunlight or rain.

In addition, various 3D scanning techniques can be employed in different contexts to produce a digital survey that accurately reflects reality to varying degrees of precision.

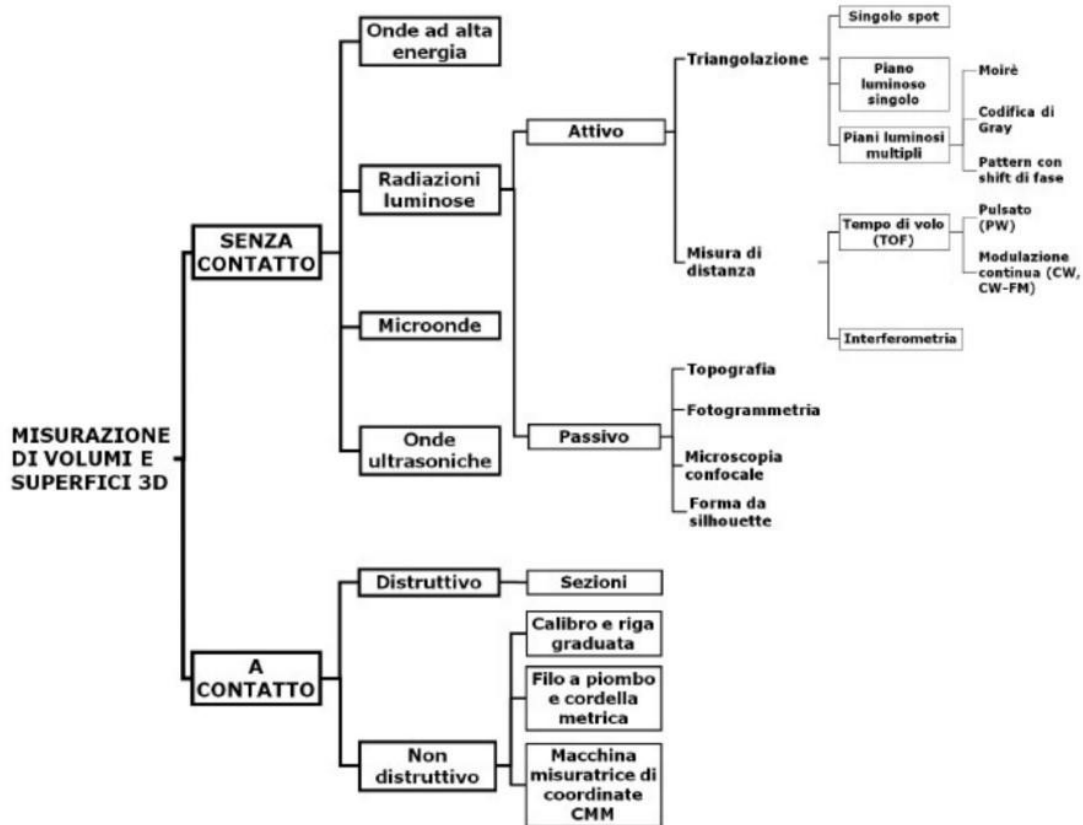


FIGURE 4 - SCHEMA OF 3D ACQUISITION TOOLS - RUSSO, REMONDINO, GUIDI

1.4 BIM TO BEM

The BIM (Building Information Modeling) to BEM (Building Energy Modeling) process involves using information from a building's BIM model to create a virtual energy model of the building for analysis and optimization of energy performance. The data that can be transferred from BIM to BEM include:

Building geometry: The 3D geometric model of the building can be transferred from BIM to BEM. This includes the walls, floors, ceilings, roofs, windows, and doors.

Thermal properties of building materials: BIM models can include information about the thermal properties of building materials, such as insulation, roofing, walls, and windows. This information can be transferred to BEM models to calculate the energy consumption and efficiency.

Lighting information: BIM models can include information about lighting fixtures, their location, and type. This information can be transferred to BEM models to calculate lighting loads and energy consumption.

HVAC system information: BIM models can include information about heating, ventilation, and air conditioning (HVAC) systems, including the location of HVAC equipment, air ducts, and vents. This information can be used in BEM models to calculate heating and cooling loads and energy consumption.

Occupancy and usage information: Information about the occupancy of the building, such as the number of occupants, their activities, and the schedule of their activities, can be used in BEM models to calculate energy consumption based on the actual usage of the building.

Weather data: BEM models rely on data about the local weather conditions, such as temperature, humidity, and solar radiation. This data can be obtained from external sources and used in BEM models to calculate the energy consumption of the building.

Overall, the transfer of such data from BIM to BEM can provide a more comprehensive and accurate assessment of the building's energy performance and sustainability.

1.4.1 Historical buildings' energy Retrofitting research assessment

Historical buildings constitute significant contributors to energy consumption and greenhouse gas emissions. Therefore, it is crucial to retrofit these buildings and enhance their energy efficiency. The challenge at hand is to reduce their environmental impact while preserving their historical significance. Several studies regarding assessment of their energy performance and retrofitting techniques have been performed so far:

Assessing energy performance:

Several studies have proposed methods for assessing historical buildings' energy performance to identify the best retrofitting options. Zhang et al. (2019) proposed a methodology based on building energy simulation and multi-objective optimization. Mavrogianni et al. (2018) proposed a comprehensive method for assessing the energy performance of historical buildings based on field measurements and building energy simulation. These studies highlight the importance of understanding the energy consumption patterns of historical buildings before implementing retrofitting measures.

Sustainable retrofitting techniques:

Several sustainable retrofitting techniques have been proposed for historical buildings, such as passive design, envelope insulation, and the use of renewable energy sources. De Angelis et al. (2019) proposed a retrofitting strategy based on the use of a hybrid ventilation system and an innovative insulation system. Pons et al. (2017) proposed a retrofitting strategy based on a passive design approach and the use of photovoltaic panels. These studies demonstrate that a combination of different retrofitting techniques may be necessary to achieve significant energy savings in historical buildings.

Challenges and barriers:

Several challenges and barriers hinder the energy-efficient retrofitting of historical buildings, such as the lack of appropriate retrofitting techniques, the complexity of historical buildings' structures, and the potential impact of retrofitting on their cultural heritage value. Shao et al. (2019) identified several barriers to the energy-efficient retrofitting of historical buildings, such as the lack of knowledge about the buildings' construction and the difficulty in obtaining permits for retrofitting. These challenges must be addressed to ensure the successful retrofitting of historical buildings.

Ultimately improving the energy efficiency of historical buildings is a complex and challenging task that requires a comprehensive approach. To accomplish this goal, it is essential to assess the energy performance of historical buildings, identify appropriate retrofitting techniques, and overcome any obstacles to retrofitting. Further research is necessary to develop more effective and sustainable retrofitting techniques that consider the specific needs and characteristics of historical buildings. By implementing these measures, the environmental impact of historical buildings can be reduced while their cultural heritage value is preserved for future generations.

1.4.2 Software programs available for building energy modeling

There are several software programs available for building energy modeling, some of which are listed below:

EnergyPlus: EnergyPlus is a free building energy simulation software program developed by the U.S. Department of Energy. It is used for modeling the energy

performance of buildings and for assessing the impact of various energy-saving measures.

OpenStudio: Open Studio is an open-source building energy modeling software program that is used for creating and analyzing energy models of buildings.

eQUEST: e QUEST is a free building energy modeling software program that is widely used by engineers and architects for designing and analyzing building energy systems.

TRNSYS: TRNSYS is a comprehensive building energy modeling software program that is used for simulating the performance of renewable energy systems, such as solar and geothermal systems.

IES Virtual Environment: IES Virtual Environment is a building energy modeling software program that is used for simulating the energy performance of buildings and for analyzing various energy-saving measures.

DesignBuilder: Design Builder is a commercial building energy modeling software program that allows users to create detailed 3D models of buildings and to simulate their energy performance.

HAP: HAP (Hourly Analysis Program) is a building energy modeling software program that is used for analyzing the energy performance of HVAC systems in buildings.

1.4.3 The Benefits of Using IESVE for Building Energy Modeling

The IES Virtual Environment (IESVE) is a widely used and highly regarded building energy modeling software program that has several features that make it a popular choice for engineers and architects. Some of the advantages of IESVE are:

Comprehensive modeling capabilities: IESVE allows users to create detailed 3D models of buildings and to simulate their energy performance under various scenarios. The software program includes a range of modeling capabilities, such as thermal modeling, lighting modeling, and HVAC modeling.

Sustainability and environmental analysis: IESVE include tools for sustainability and environmental analysis, allowing users to assess the environmental impact of their building designs and to identify areas for improvement.

Accurate simulation results: IESVE uses advanced simulation algorithms and models to provide accurate energy performance predictions for buildings.

Integration with other software programs: IESVE can be integrated with other software programs, such as Autodesk Revit and SketchUp, allowing users to import building models and to export results for further analysis. One of the main objectives of this research is to assess the degree of compatibility between Revit and IESVE, and to identify the kinds of data that can be transmitted from Revit to IESVE throughout the BIM to BEM transformation.

1.5 Case Study: Borgo Pirelli

1.5.1 Historical Overview

After the First World War, large companies tried to cope with the shortage of housing by creating the so-called "Popular Districts". These neighborhoods were created with the intention of harmoniously linking workers with the companies they worked for, improving their housing conditions and their quality of life.

Borgo Pirelli is a workers' village built between 1920 and 1923 based on the design of the architect Giacomo Loria and commissioned by the Pirelli company, which relied on the work and subsequent management of the Istituto Case Popolari of Milan. The village consists of 26 two-story villas irregularly arranged and attributable to 5 different types based on the function performed in the company by their occupants. Each villa contains two to four apartments built on a former agricultural land between Via Sarca and Via Luigi Emanuele, Franco Sacchetti and Piero Pirelli, in the north of the city of Milan. On the north-western edge of the Village, a four-story Liberty-style building called "La Casona" was built. This building also provided space on the ground floor for some shops.



FIGURE 5: HISTORICAL PAINTING OF BORGO PIRELLI. THE BUILDING MODEL DEVELOPED RESEMBLES THE ROMANTIC SHAPE OF THE ENGLISH GARDEN CITY.

With the decline of the Pirelli company, the houses were sold to the Lombardy Region and subsequently to ALER, Lombard Residential Company. Over the years, Borgo Pirelli has shown several maintenance problems, such as water infiltration from the roofs, mold inside the villas, among others. Only in 2019, more than 100 maintenance works were carried out.



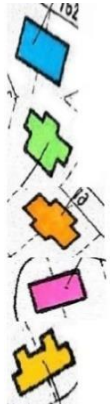
FIGURE 6: PHOTOGRAPH TAKEN FROM COLLINA DEI CILIEGI.

1.5.2 Borgo Pirelli an Important Case Study in Preserving Historical Architecture

The Borgo Pirelli area was historically a working-class neighborhood that was neglected and overlooked for many years. The Borgo Pirelli restoration project is important because it is a model for sustainable urban development. The restoration project aims to revitalize the area and provide new opportunities for the local community and preserve the historic architecture and cultural heritage of the area. The buildings in Borgo Pirelli date back to the early 20th century and are significant examples of industrial architecture from that period. The restoration will ensure that these buildings are conserved and adapted for modern use, while still retaining their original character and charm.

1.5.3 - Description of the Villas and Villa Types

The villas are mainly divided into semi-detached houses (with a main entrance and stairs dedicated to each of the two units) and four-family houses (a type characterized by the presence of a single entrance from which you can access a single common staircase for all four apartments).



Type "A" - Major Semi-detached Villa (1)

Type "B" - Minor Four-family Villa (11)

Type "C" - Major Four-family Villa (9)

Type "D" - Minor Semi-detached Villa (4)

Type "E" - Intermediate Semi-detached Villa (2)

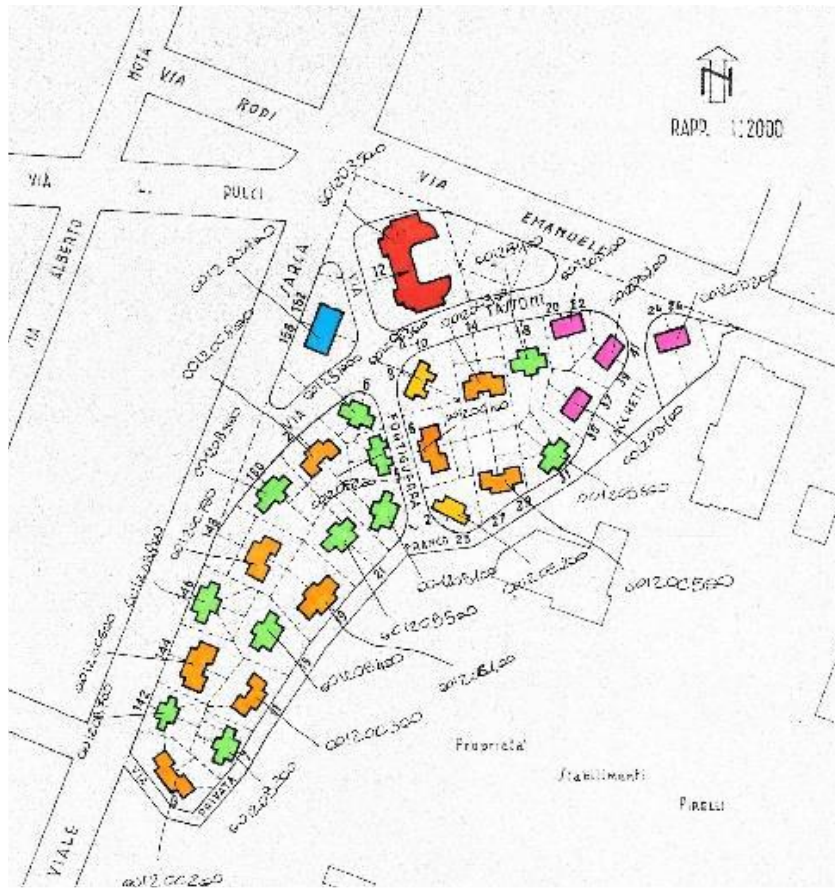


FIGURE 7: VILLA TYPES - BORGO PIRELLI

1.5.3.1 Typology A

(Viale Sarca 158-162)

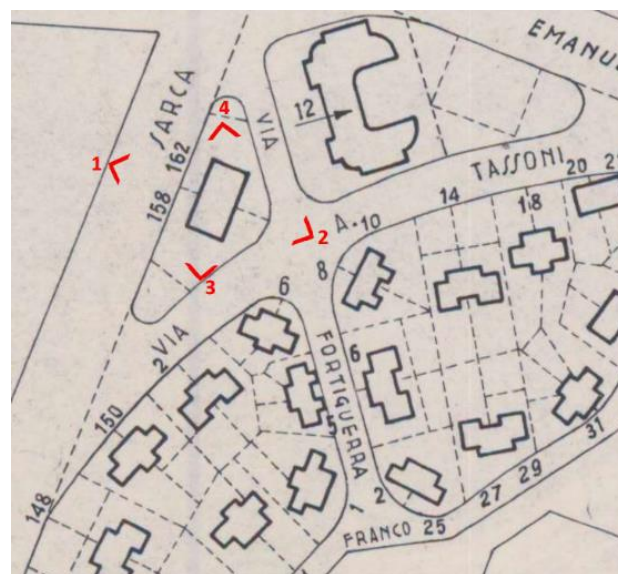
Building perimeter 61.92 m

Height perimeter 8.85 m

facade surface 547.99 m²

covered area 174.48 m²

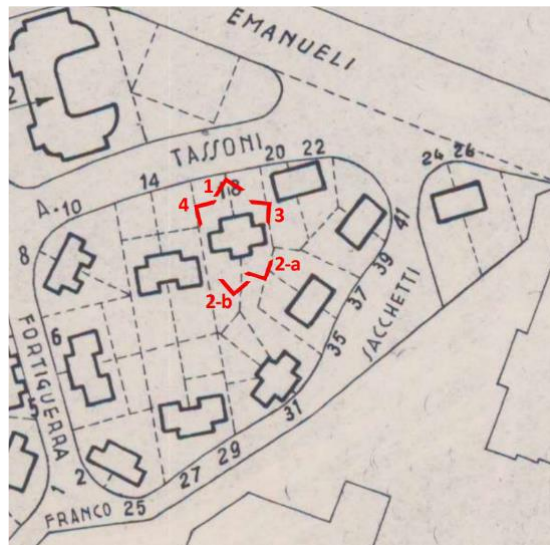
Number of windows 48



1.5.3.2 Typology B

Via Tassoni 6, 18 – Via Fontiguerra 1, 5 – Via Sacchetti 15, 21, 31 – V.le Sarca 142,
246,150

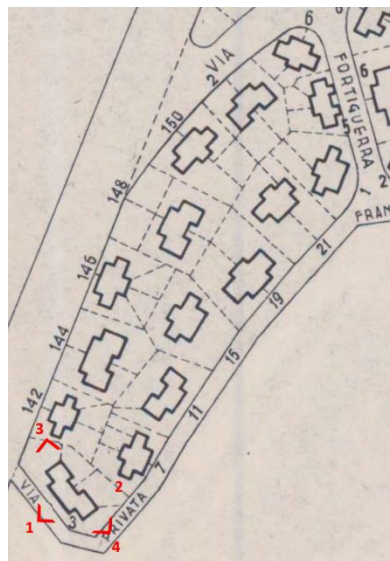
<i>Building perimeter</i>	52.54 m
<i>Height perimeter</i>	8.29 m
<i>facade surface</i>	435.56 m ²
<i>covered area</i>	131.07 m ²
<i>Number of windows</i>	37



1.5.3.3 Typology C:

Via Fonteguerra 6- Via Sacchetti 3, 11, 19, 27 – Via Sarca 144, 148 – Via Tassoni 2, 14

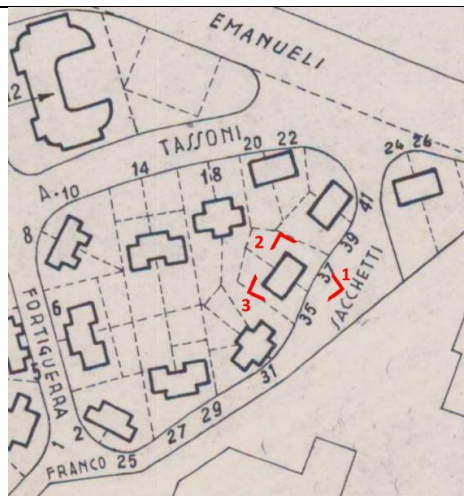
<i>Building perimeter</i>	61.65 m
<i>Height perimeter</i>	8.23 m
<i>facade surface</i>	507.38 m ²
<i>covered area</i>	189.22 m ²
<i>Number of windows</i>	43



1.5.3.4 Typology D:

Via Sacchetti 35+37, 39+41 – Via Tassoni 24+ 26, 20+ 22

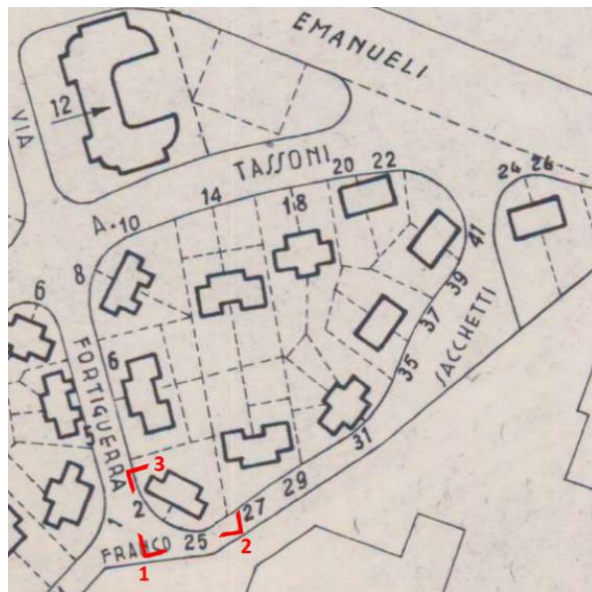
<i>Building perimeter</i>	48.10 m
<i>Height perimeter</i>	8.44 m
<i>facade surface</i>	405.96 m ²
<i>covered area</i>	132.39 m ²
<i>Number of windows</i>	36



1.5.3.5 Typology E:

(Via Fortiguerra 2 + Via Sacchetti 25 – Via Tassoni 8 + 10)

<i>Building perimeter</i>	58.82 m
<i>Height perimeter</i>	7.91 m
<i>facade surface</i>	465.27 m ²
<i>covered area</i>	156.44 m ²
<i>Number of windows</i>	40



1.5.4 Case Study: Villa in Via Sarca 162

This case study focuses on a villa located at the start of Via sarca 162, which is classified as a type A building. It faces Via Sarca and Via Nicolo Fortiguerra. The villa itself is rotated about 38 degrees in a clockwise direction from the north-south axis, and its front is oriented towards the northwest. It boasts a large garden, which sets it apart from the neighboring villas. The building is comprised of two above-ground levels, a basement, and an attic.



FIGURE8: VILLA IN VIA SARCA 162 - BORGO PIRELLI

The building is currently occupied in two levels. The two-story villa has distinctive cornices separating the floors, ornate friezes on the main façade, and white lacquered wooden windows. The walls are made of solid bricks with a thickness of around 41 cm and are plastered, while the staircase's load-bearing walls are approximately 27 cm thick and made of solid bricks with 2 heads. The villa lacks any thermal insulation in both the perimeter walls and ceilings, with the basement floor being unusable and abandoned. Despite these issues, the villa, along with the Pirelli Village, is a unique example of construction in the city of Milan.



FIGURE9: VILLA IN VIA SARCA 162 - BORGO PIRELLI-NORTH WEST VIEW



FIGURE 11: VILLA IN VIA SARCA 162 - BORGO PIRELLI-NORTH EAST VIEW



FIGURE 10: VILLA IN VIA SARCA 162 - BORGO PIRELLI-SOUTH VIEW



FIGURE 11: VILLA IN VIA SARCA 162 - BORGO PIRELLI-INTERIOR VIEW

1.5.5 Orthophoto generation

The goal of the photographic collection was to store photographic material and generate orthophotos for a subsequent evaluation of the external conditions of the villa's facades to analyze degradation states and assess possible interventions. An orthophoto is simply the straightening of a photograph to make it an orthogonal projection at a certain scale.

As can be seen from the photographs, the entire perimeter of the structure is surrounded by vegetation. Tall trees and uncultivated hedges have made surveying activities difficult. Making the work more complex is the position of the villa itself in relation to the entire Borgo Pirelli. Located at an angle and directly facing Via Sarca, we were unable to perform the photographic collection adequately. To take photographs that can then be used to generate orthophotos, multiple shots from the same point at different angles must be taken, considering the time of day and weather conditions.

When taking photographs for orthophoto generation, it is important to choose a time of day when the sunlight does not directly hit the facade being captured or create shadows on the facades. The photographs used in this project were taken in May, and despite the sunny weather, there were no issues caused by direct solar radiation on the facades. To create the orthophotos, RDF software was used, which involves several steps such as identifying horizontal and vertical lines, selecting the resampling area, real sizing, selecting bilinear interpolation, and saving the corrected image. To overcome the limitations of the software, the "crop perspective" function of Photoshop was used. As it was not possible to capture all the facades in their entirety with the camera, a point cloud of the villa facades was used.



FIGURE 12: VILLA IN VIA SARCA 162 - BORGO PIRELLI-EAST VIEW ORTHOPHOTO



FIGURE 13: VILLA IN VIA SARCA 162 - BORGO PIRELLI-WEST VIEW ORTHOPHOTO

1.5.6 Milan Borgo Pirelli Climate Analysis

Milan has a mid-latitude humid subtropical climate, categorized as Cfa in the Köppen climate classification. The weather is comparable to that of the inland plains in Northern Italy, characterized by hot and humid summers, and cold and misty winters. Due to the presence of the Alps and Apennine Mountains, Milan is safeguarded from prevailing weather patterns originating from Northern Europe and the sea. The city is frequently covered in thick fog.

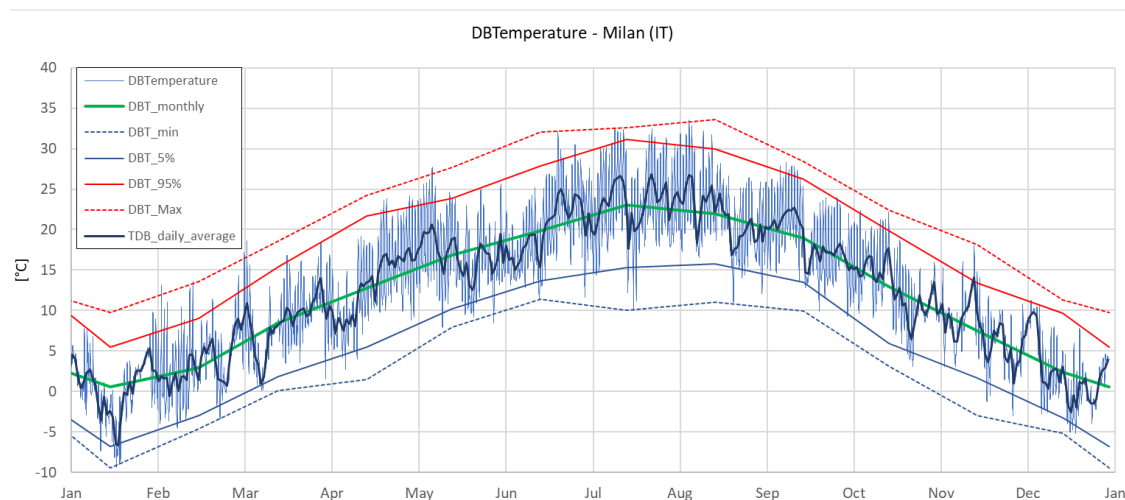


CHART 1 OUTDOOR DRY BULB TEMPERATURE

the graph displays the daily mean temperatures falling below the freezing point during winter, despite the monthly averages staying above it. January is the chilliest month with the latter half posing the greatest challenge for heating systems.

During summer, the Foehn winds may cause abrupt temperature surges. Additionally, the humidity levels remain high during the warmer months, with peak temperatures exceeding 30 °C. This season is usually marked by clear skies and an average of 13 hours of daylight. However, when precipitation occurs, there is a higher likelihood of thunderstorms and hailstorms.

The spring and autumn seasons are generally pleasant, with temperatures ranging from 10 to 20 °C. These seasons are characterized by more rainfall, particularly in April and May. Throughout the year, the relative humidity typically fluctuates between 45% (comfortable) and 95% (very humid), seldom falling below 27% (dry), and sometimes soaring up to 100%.

The violet bars clearly show that heating is in high demand to maintain internal temperatures within a comfortable range for users. Chart 3 depicts an adaptive comfort chart that evaluates comfort based on the perceived operative temperature and outdoor temperature. The comfort zone is divided into three non-symmetric categories, with CAT I representing the highest level of expectations for a fragile and sensitive environment. CAT I, CAT II, and CAT III have different ranges of acceptable temperatures. The mean running temperature (T_{rm}) is calculated as a weighted mean of the previous 7-day daily outdoor air dry-bulb temperature (T_{od}). The blue dots on the chart illustrate the relationship between outdoor temperature and adaptive comfort temperature.

Passive design strategies can maintain a comfortable indoor temperature during hot days, but they are insufficient during cold days. Additional strategies, such as HVAC design, are necessary for maintaining a comfortable temperature. However, this discussion will focus only on passive strategies for both summer and winter.

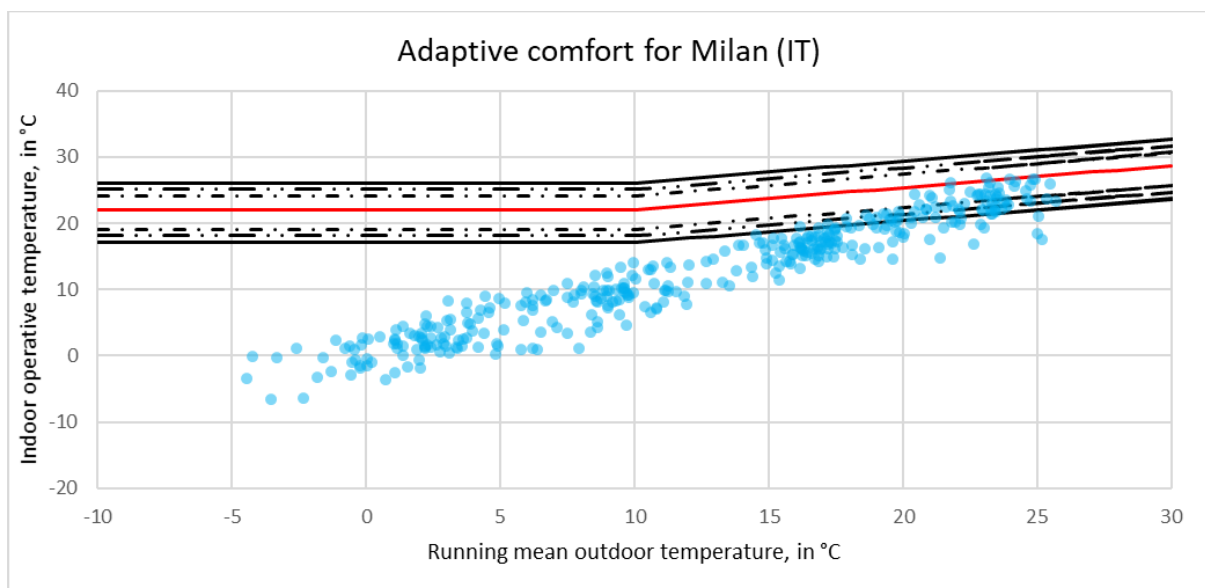


CHART 2 ADAPTIVE COMFORT

It is evident that many of the blue dots lie below the minimum comfort boundary (CAT III), indicating that the selected climate requires special attention to meet heating needs. Additionally, less than 3% of the data discretized aligns with the ideal thermal comfort line represented by the red line.

The subsequent graph was created utilizing data output from Climate Consultant software, displaying the average of Milan's total daily irradiation and its ratio in four

main directions as well as one horizontal direction. During hot months, the average irradiation on horizontal surfaces is greater, and on vertical surfaces, the west side receives slightly more irradiation compared to other directions.

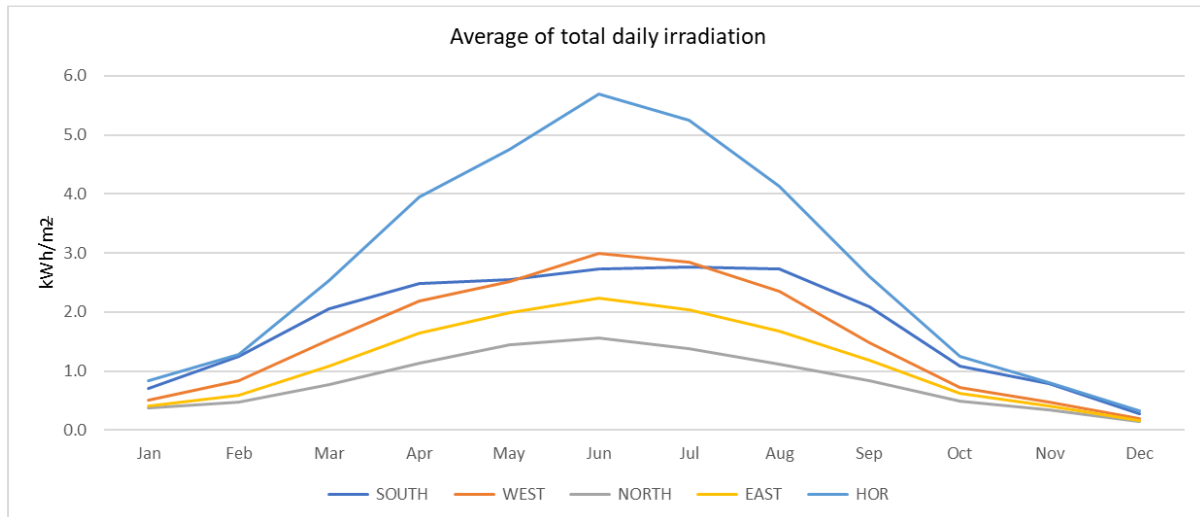


CHART 3 AVERAGE OF TOTAL IRRADIATION

The next chart shows the ratio of direct irradiation on total (DIR/TOT). It is less than total due to diffusion and reflection of surfaces.

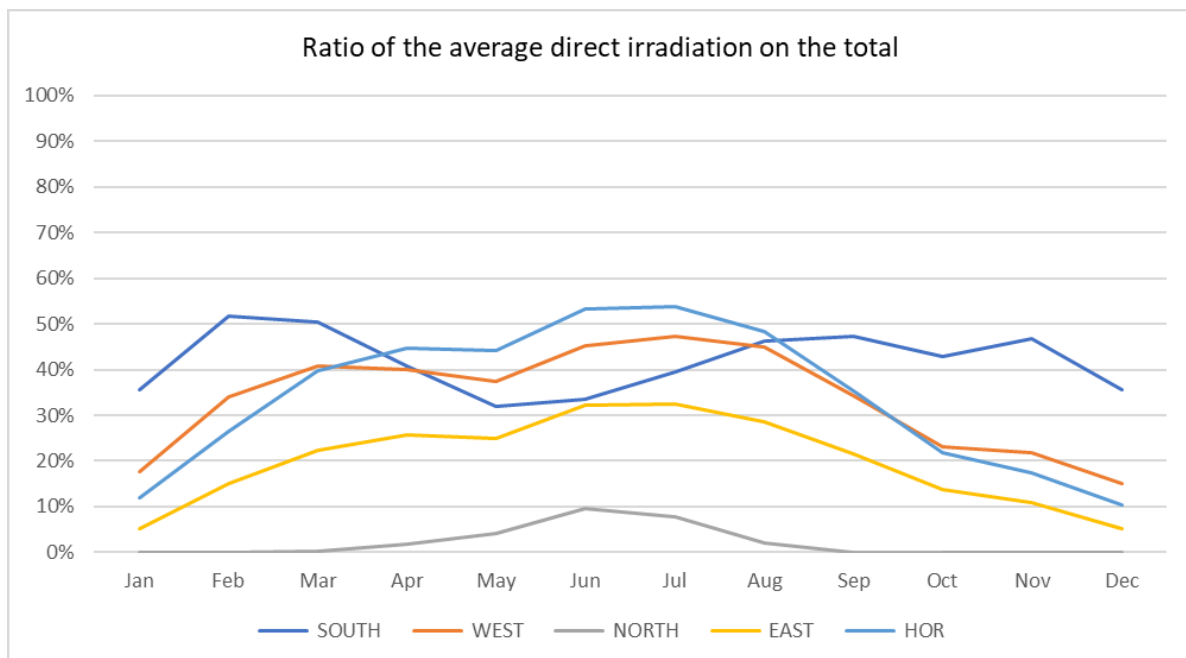


CHART 4 RATIO OF AVERAGE DIRECT IRRADIATION ON TOTAL

Finally, wind is generally absent in Milan, being normally described as “calm to gentle breeze”, rarely exceeding 30 km/h, except during summer thunderstorms. The

following images present wind directions collected from Climate Consultant) and the chart produced from the climate data collected.

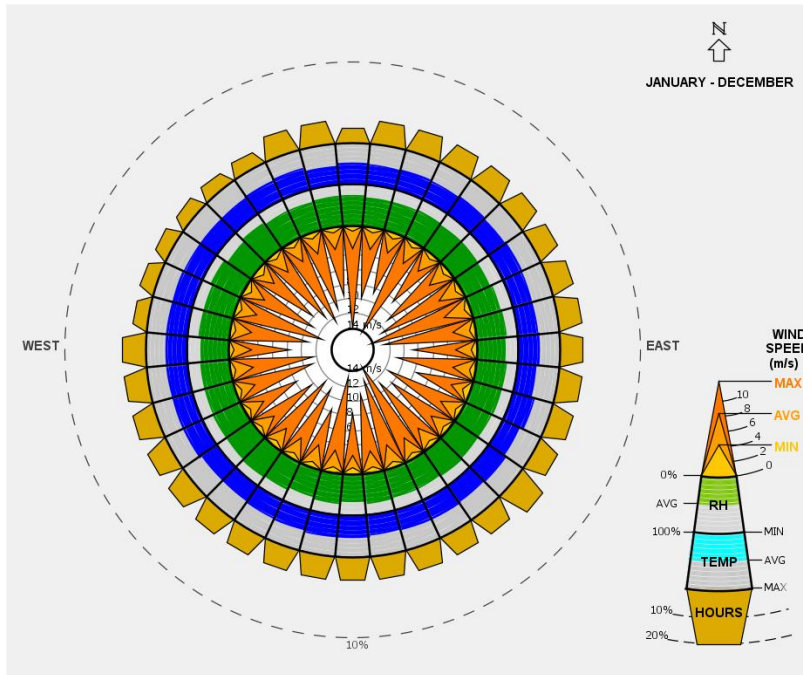


CHART 5 WIND VELOCITY

Comparing both figures, it is clear how the result is convergent to wind blowing towards east.

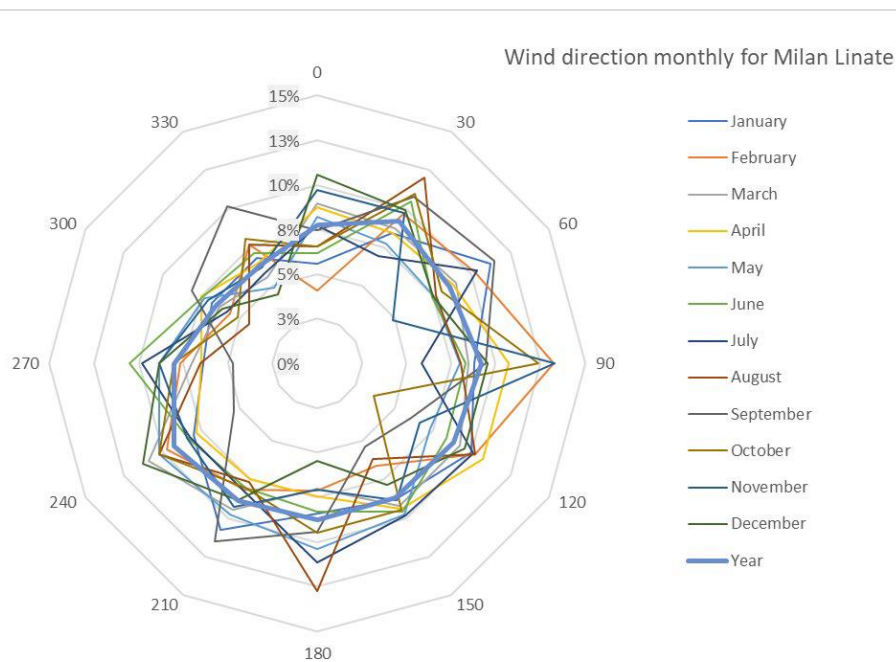


CHART 6 WIND RADAR FOR MILAN LINATE

Chapter 2 Survey and Data Processing

2.1 Purpose and Methodology of the Survey

A survey was conducted in March 2022 on the houses in the Borgo Pirelli area using a laser scanner to create a geometric representation of the current state of the properties. The survey was conducted externally for all villas. The purpose of the survey was to generate point clouds for each measurement taken at local stations. To ensure accurate alignment, the clouds were subsequently aligned. The instrument's main parameters were set to define the speed and quantity of scans required for the specific objective.

2.1.2 Importance of Digital Surveying Techniques in Construction Industry

The chapter not only reports the survey carried out but also analyses the main laser technologies currently in existence, highlighting their different characteristics and fields of use. Furthermore, it provides a theoretical treatment of the main surveying methods. The continuous development and evolution of three-dimensional digital modeling has led to the use of innovative surveying techniques that allow reproducing digital visualizations of buildings, becoming an important tool for surveying existing built heritage. In the construction industry, the interest in digital surveying techniques and methodologies is related to the need to carry out accurate three-dimensional modeling to create a digital database of existing heritage. This would provide a repertoire of models containing all the necessary information for building management in all phases of the life cycle, including maintenance and restoration interventions. The surveying technique to be used is chosen depending on the type of building to be surveyed and any peculiarities and characteristics of the site.

2.1.3 Techniques and tools for three-dimensional surveying

The theoretical notions reported in the following paragraphs are derived from a re-elaboration of the contents of the article "Main techniques and tools for three-dimensional surveying in the archaeological field" - M. Russo, G. Guidi, F. Remondino - 2011. The chapter further explores the main methods of application and the operating principles of the tools used to carry out three-dimensional surveys, highlighting their strengths and weaknesses.

2.1.3.1 Types of Three-Dimensional Sensors

According to the chapter, "three-dimensional sensors are instruments that allow generating a 3D image of the scene they frame. Sensors based on the use of light radiation can be divided according to the nature of the light used to perform the measurement. If it is natural light, the measurement methods are called "passive" (photogrammetric technique, theodolites, etc.); if instead, the light is coded in such a way as to play a role in the measurement process, it is called "active sensors" (laser scanners, structured light projection tools, radar, total stations, etc.)".

2.1.3.2 The Leica RTC360 Laser Scanner as an Active Sensor

The laser scanner used in the survey conducted in March 2022 falls into the category of "active sensors". The purpose of the survey was to generate point clouds for each measurement taken at local stations. The Leica RTC360 laser scanner was used because of its ability to generate millimetrically precise point clouds, which can represent the buildings in three dimensions. However, it is important to position the scanner accurately to ensure that the point clouds are aligned correctly.

2.1.3.3 Laser Scanning with Leica RTC 360

Laser scanners could quickly measure the location of many points. This generates a point cloud consisting of millions of points in three dimensions (x, y, z). To perform a laser scanning survey, a project is created where the laser points are placed on a plan. Each survey station generates a point cloud that must be aligned with the others on-site during the survey. The presence of fixed obstacles, such as trees, furniture, and people, can compromise the survey process by creating shadows that affect the captured data. Translucent objects, like mirrors and glass, can produce false results due to the behavior of the light radiation that reaches them. The digital survey of the villa located at Via sarca 162 in Borgo Pirelli was conducted using the Leica RTC 360 laser scanner, which can measure over 2 million points per second, generating a 3D-colored point cloud in under 2 minutes. This laser scanner utilizes VIS ("Visual Inertial System") technology to improve the accuracy of station positioning and subsequent alignment.



FIGURE 14 - LEICA RTC360 ([HTTPS://LEICA-GEOSYSTEMS.COM/IT-IT/PRODUCTS/LASER-SCANNERS/SCANNERS/LEICA-RTC360](https://leica-geosystems.com/it-it/products/laser-scanners/scanners/leica-rtc360))

The Leica RTC360 laser scanner was used to carry out the survey. This instrument can provide a millimetrically precise point cloud representing the buildings in three dimensions. The instrument is static and requires positioning on a tripod. To avoid interference with obstacles that may affect the accuracy of the data, certain precautions were taken, such as avoiding trees and translucent or transparent surfaces.

To avoid interference with obstacles that may affect the accuracy of the data, certain precautions were taken during the survey. These precautions included avoiding trees and translucent or transparent surfaces. Furthermore, the instrument's main parameters were set to define the speed and quantity of scans required for the specific objective.

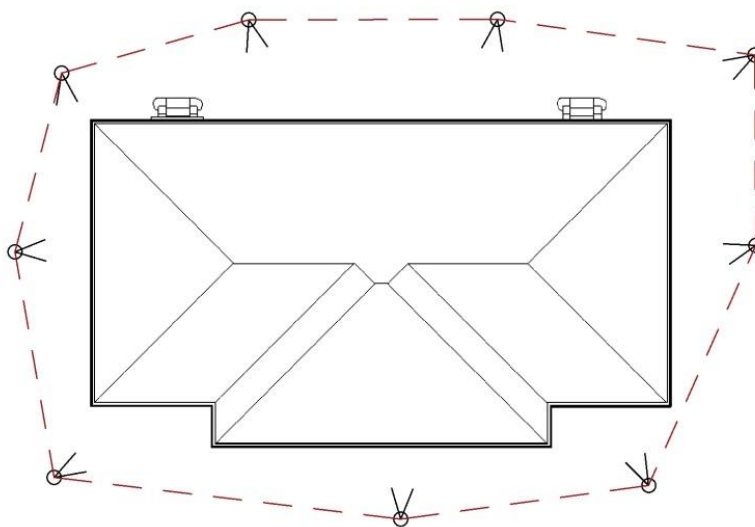


FIGURE 15- POSITIONING OF LASER SCANNER SURVEY STATIONS

2.1.3.4 Previewing and editing the survey using Cyclone

After completing the scans from all stations, the instrument generated the point cloud, and thanks to the dedicated Cyclone application, the survey conducted could be previewed and edited on mobile devices. This allowed for the identification of any inaccuracies due to incorrect positioning of the stations or unsuccessful scans, thus reducing the time required for reprocessing in the next phase of the survey.

The Leica RTC 360 was used to conduct a laser scanning survey both inside and outside of the villa. The instrument was placed at various points throughout the structure using a specific process, which included mounting the laser scanner on a tripod and connecting it to a tablet via an internet connection. The Cyclone Field 360 application was then used to create a new work project and establish the scanning density. Each scan took approximately two minutes, and photographs were taken and put together with each point cloud. After scanning all the points, the Cyclone Field 360 application was used to align the clouds on-site, visualize them in 3D, and validate the project. Finally, data processing was done in the laboratory with Cyclone Register 360. Cyclone is a software suite that offers individual software modules, including Cyclone Field 360 for point cloud survey and management, and Cyclone Register 360 for dense cloud alignment and report creation, among others. This software suite is highly customizable to meet different needs.

2.1.4 Reverse Modeling for generating digital representation of existing buildings

The processing of the data collected during the survey and the subsequent generation of the three-dimensional model of the point cloud is called Reverse Modeling. This involves obtaining the digital representation of the existing real building, which is then used for the BIM modeling of the buildings. The scans completed with the instrument are registered according to the scanner's reference system, and an alignment phase is performed to generate the final three-dimensional model.

2.1.5 Different approaches for alignment phase during Reverse Modeling

To perform alignment, three methodological approaches can be used, including alignment between adjacent shots, alignment between shots with fixed targets or recognizable points, and alignment managed by external sensors. Shadow zones present within the scene can limit the generation of the cloud, but this can be overcome by integrating the data collected by the scanner with a photographic campaign and

carrying out the survey under optimal weather and visibility conditions for the site context.

Alignment between adjacent shots: normally used when instruments perform a triangulation survey and involves two distinct alignment phases that aim to optimize the differences between points in the cloud.

Alignment between shots with fixed targets or points recognizable and clearly visible from different positions: typically used with time-of-flight scanners, thanks to reference points, it is possible to calculate the rotation-translation that allows for point alignment.

Alignment managed by external sensors: this is the fastest method that limits post-production work, but depending on the external sensor used, the success of the alignment and the final quality of the three-dimensional point cloud can vary significantly.

Among the main problems of data reprocessing related to image acquisition are the shadow zones present within the scene that can significantly limit the generation of the cloud. To overcome these problems, it is possible to integrate the data collected by the scanner with a photographic campaign and carry out the survey under optimal weather and visibility conditions for the site context.

2.2 Data Processing for Point Cloud Generation

The process of creating a digital model for a building involves several important steps, including data processing. This chapter discusses the optimization and alignment phases of the data processing stage. One of the essential tools used in this process is the Cyclone software, which provides a range of tools to manage and edit data from the instrument.

2.2.1 Optimization and Alignment Phases of Data Processing with Cyclone Software

The use of the RTC360 scanner and the dedicated Cyclone application has facilitated the preview and editing of the survey, reducing the time required for reprocessing.

Reverse Modeling is used to generate the digital representation of the existing building, which is then used for BIM modeling.

The alignment phase involves using different methodological approaches, and shadow zones within the scene are addressed by integrating scanner data with a photographic campaign.

The optimization phase involves mesh decimation to simplify the point cloud while maintaining a certain level of precision. The level of detail varies depending on the density of the point cloud and the decimation performed. Regularizing the polygonal mesh is essential before exporting the point cloud for modeling on other software. Cyclone software is used to align the point cloud and export the data in formats compatible with BIM modeling.

The alignment phase is crucial to ensure the accuracy and reliability of the point cloud. Cyclone provides different execution modes to align the point cloud, including Auto Target, Auto Cloud, Smart Align, and Pre-Registered. The program has four fundamental steps that allow the editing of data coming from the instrument to be managed. The optimization phase involves refining the digital model output, setting a unique coordinate system to orient the project, and making further changes to manage the activation of the point cloud.

2.2.2 Importing and Cleaning Point Cloud on Autodesk RECAP

The utilization of point clouds is crucial in simplifying the modeling process within the BIM environment for this project. The overall perspective of the building can be retained while achieving reliable outcomes. Due to software licensing limitations, we exported the Cyclone Register-generated e57 file to Autodesk's Recap software for optimal processing of 3D survey data from laser scanners or drones. RECAP supports various laser scanning file formats, including .fls, .fws, .ptg, .ptx, .las, .clr, .rds, and .e57, streamlining the Scan-to-BIM process. We encountered challenges during the survey process that impeded the scanning of the villa's facades. To improve the point cloud's visibility, we conducted cleaning by eliminating or concealing unwanted points.



FIGURE 16- TOP VIEW OF THE UNCLEANNED POINT CLOUD OF THE TYPE A BUILDING IN VIA SARCA 162
AND ITS CONTEXT



FIGURE 17- PERSPECTIVE VIEW OF DECIMATED POINT CLOUD OF BUILDING TYPE A IN VIA SARCA 162

2.2.3 Exporting Optimized and Aligned Point Cloud for BIM Modeling

After optimizing and aligning the point cloud, it is possible to export it to other software for modeling purposes. However, it is important to establish quality criteria to ensure that the output point cloud accurately represents the key features of the building. Cyclone software includes tools that enable the creation of a customized project report. To create a digital model of a building, the data processing stage is crucial. By using the RTC360 scanner and Cyclone software, this process can be simplified, and the optimization and alignment phases guarantee the point cloud's accuracy and reliability. Cyclone software also provides tools for managing and editing data, defining initial settings, modifying processing parameters, and generating customized project reports. Once the final output is exported to other software, it ensures a realistic representation of the building's key features.



FIGURE 18- NORTH VIEW OF CLEANED POINT CLOUD OF BUILDING TYPE A IN VIA SARCA 162



FIGURE 19- EAST VIEW OF CLEANED POINT CLOUD OF BUILDING TYPE A IN VIA SARCA 162



FIGURE 20- SOUTH VIEW OF CLEANED POINT CLOUD OF BUILDING TYPE A IN VIA SARCA 162



FIGURE 21- WEST VIEW OF CLEANED POINT CLOUD OF BUILDING TYPE A IN VIA SARCA 162

Chapter 3 BIM Modeling with Revit

3.1 Point Cloud Import

The process of generating a detailed BIM (Building Information Modeling) model based on a point cloud includes different steps. The first step is to import the point cloud file into a BIM software, such as Autodesk Revit. This allows for easy interaction with the point cloud and the ability to generate primary geometries based on the point cloud, which allows for easy interface with Autodesk ReCap.

3.2 Point Cloud Import

The next step is to generate primary geometries on the point cloud, followed using system families and creating, parameterizing, and creating local families. The level of detail required for the model should be established beforehand, and it is important to use the appropriate types of families with the necessary accuracy. Point clouds allows for easier understanding of building geometries and stratigraphy compared to traditional survey techniques. The modeling process also involves verifying that the point cloud and geometric model origins coincide to create a correctly oriented model.



FIGURE 23- IMPORT THE POINT CLOUD FILE INTO REVIT AND GENERATION OF PRIMARY GEOMETRY

3.3 Manage Data Using Point Clouds

Point clouds allow for easier understanding of building geometries and stratigraphy compared to traditional survey techniques. Once inserted into the program, point clouds can be recognized and interacted with using snap commands, and they can interact with the reference planes of the model to visualize building plans, sections, and elevations. Point clouds cannot be edited once inserted into the program, but they can be moved, rotated, and provide snap references for modeling.



FIGURE 24- INTERACTION WITH THE POINT CLOUD IN REVIT

3.3 Managing model tolerances

The level of precision and allowable tolerances when modeling based on a point cloud could be quite important. While creating a BIM representation of a building, the focus is more on information management rather than accurately representing every architectural detail. The maximum allowable deviation is defined, and modeling is performed to reduce errors as much as possible. Families are a fundamental concept of the BIM methodology used to create and customize the elements to be included in the model.

3.4 Define and Insert Loadable Families

Different methods for modeling windows depending on whether they were for the apartments or for other glass components have been utilized. For the apartment windows, they created a loadable family that could correctly represent the shutters and

bolts, increasing the reliability of the results. A new family is created from the "metric window" model file for the other glass components, making it as faithful to reality as possible to increase the precision of the energy simulation.

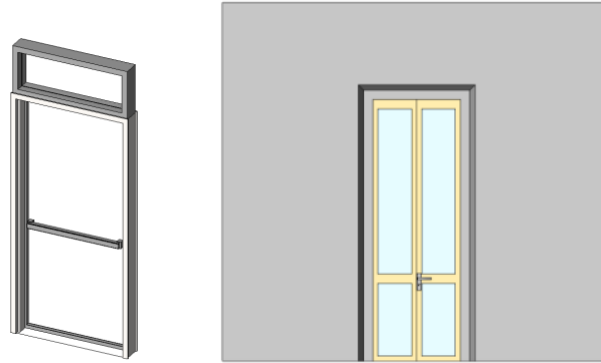


FIGURE 25- WINDOW AND DOOR LOADABLE FAMILIES

3.5 - Limits of Revit in creating architectural details:

The modeling of the buildings in the Borgo Pirelli case study encountered some issues related to the interaction between the point cloud and the modeling software, their management, and the high volume of data necessary to correctly carry out the modeling. The main problems encountered relate to the approximations related to the inclination of the walls, the modeling of the stairs, and the roof. Managing the tolerances and actual profiles of the point cloud due to the imperfections of installation was complex, and some specific components such as curtains, blinds, or shutters have been modeled in a schematic way due to the lack of available information on their technical characteristics. The building models were classified according to the level of detail achieved using the LOD (Level Of Detail) system. The Italian reference standard (UNI 11337-4:2017) was used to classify LODs, which defines the level of development and quality of the data and information present within a model. The models created for the Borgo Pirelli case study had a level of detail equal to LOD D, which means that the geometric representations were detailed and faithful to reality, and there was quantitative and qualitative information regarding the materials used for the realization of the components and families present. However, to obtain a higher LOD level, more detailed information is needed regarding the installation and laying methods of individual elements.

3.6 Final model of villa

Once the main geometry had been modeled and all the different types of families had been inserted, a 3D parametric model full of data was obtained that could be used for various energy analyses. The modeling process was very challenging due to the numerous issues that arose and the overall complexity of the villa. Since the villa was constructed in the 1930s, it has a multitude of architectural details and intricately designed building elements such as windows, doors, and other elements mentioned before.



FIGURE 26- BORGO PIRELLI-VIA SARCA 162 FINAL 3D MODEL

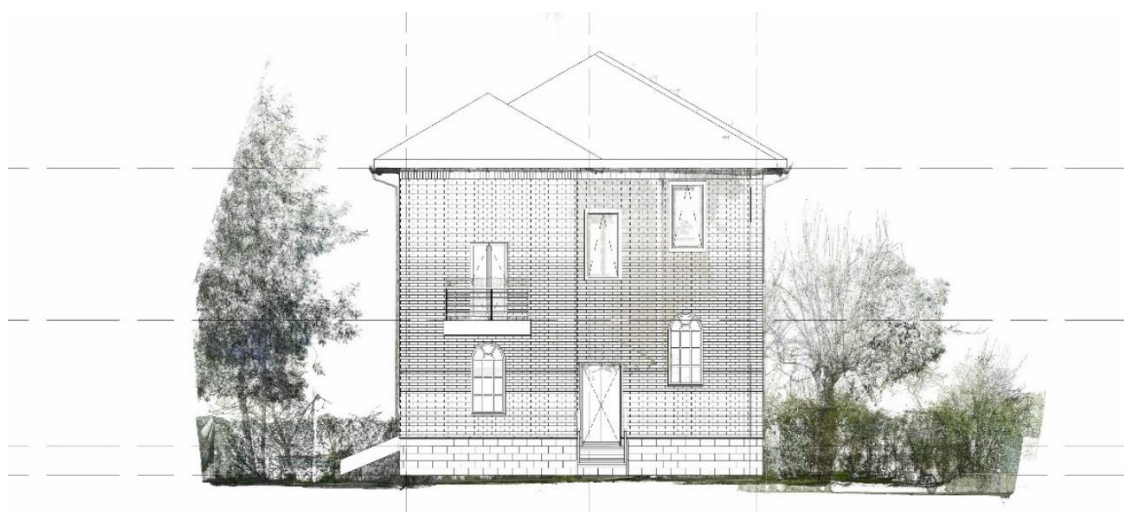


FIGURE 27- BORGO PIRELLI-VIA SARCA NORTH FACADE



FIGURE 28- BORGO PIRELLI-VIA SARCA EAST FACADE

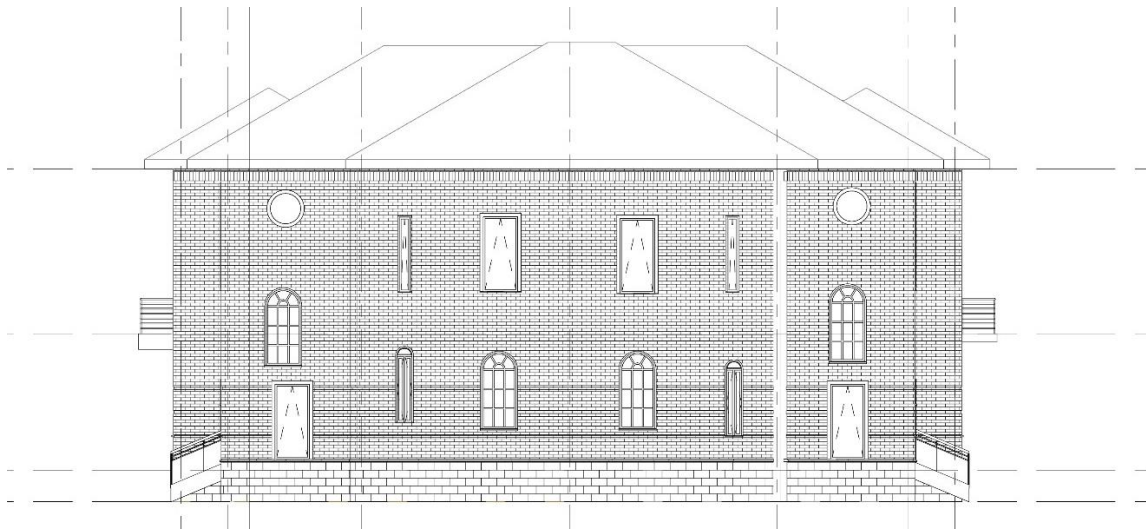


FIGURE 29- BORGO PIRELLI-VIA SARCA WEST FACADE



FIGURE 30- BORGO PIRELLI-VIA SARCA SOUTH FACADE

Chapter 4 BIM TO BEM

The BIM-to-BEM procedure is the process of transferring information from a Building Information Model (BIM) to a Building Energy Model (BEM), with the goal of creating a more accurate and detailed energy model of the building. This involves collecting data, building a BIM model, exporting it to a BEM software program, defining simulation parameters, running the simulation, optimizing the building for energy efficiency, refining the BIM model, and repeating the energy analysis. By following this procedure, you can identify energy efficiency improvements that will help to reduce the building's energy consumption and carbon emissions, while preserving its historical character, particularly when transforming a historical building from a BIM to a BEM.

4.1 Revit to IESVE Compatibility

4.1.1 Export the BIM data to a compatible format

The data exported from the BIM software needs to be converted to a format that can be read by the BEM software. Revit can export different file formats that are compatible with IESVE software. The following file formats can be exported from Revit and imported into IESVE:

gbXML (Green Building XML): This is a widely used file format for building energy analysis, and it can be exported directly from Revit. It contains detailed information about the building geometry, materials, and HVAC systems.

IFC (Industry Foundation Classes): This is an open file format that is used for sharing building information across different software platforms. Revit can export IFC files that can be imported into IESVE.

DXF (Drawing Exchange Format): This is a file format used for 2D drawings, and it can be exported from Revit. However, DXF files only contain 2D geometry, so they may not be suitable for complex building models.

DWG (AutoCAD Drawing): This is another file format used for 2D drawings, and it can also be exported from Revit. However, like DXF files, DWG files only contain 2D geometry.

The accuracy and compatibility of file formats for transferring Revit data to IESVE may differ depending on the software versions used. GBXML is the best format for importing Revit information to IESVE because it is tailored to building performance simulation, can accurately transfer all data, and has a standard structure readable by IESVE. It is compatible with multiple BIM software and can transfer both geometry and non-geometric information, accurately capturing building details and being easy to export from Revit.

4.1.2 Types of Data Transferred through the GBXML Format

gbXML (Green Building XML) is a file format used for the transfer of building information between different software applications, specifically for energy analysis and building performance simulations. Using gbXML, it is possible to transfer a variety of data from Revit to IESVE, including:

Building geometry: gbXML allows the transfer of the 3D geometric model of a building, including walls, floors, roofs, windows, and doors.

Room and space information: gbXML can transfer information about individual rooms and spaces, including their volume, area, and occupancy.

HVAC system information: gbXML can transfer information about the heating, ventilation, and air conditioning (HVAC) systems in a building, including ductwork, air terminals, and mechanical equipment.

Lighting information: gbXML can transfer information about the lighting fixtures and systems in a building, including their location, type, and intensity.

Material properties: gbXML can transfer information about the thermal properties of building materials, such as their thermal conductivity, heat capacity, and density.

Weather data: gbXML can transfer weather data, including temperature, humidity, solar radiation, and wind speed and direction.

To transfer building information from Revit to IESVE, GBXML is a file format that can accurately capture and transfer all the necessary data is required. allowing for seamless integration between the two software programs. Revit and IESVE are highly compatible when using the GBXML format for exchanging information related to building energy performance analysis.

Revit and IESVE are compatible using the GXML (Green Building XML) format, which is an open standard format for exchanging information related to building energy performance analysis.

4.1.3 BIM to BEM Interoperability

When it comes to importing data from Revit to IESVE for energy analysis and simulation, there are different considerations to consider depending on the type of data being imported. Importing geometry from Revit to IESVE is generally an efficient process, given Revit's popularity in creating 3D building models that can be easily imported into IESVE.

However, importing thermal and material properties from Revit to IESVE may not be as efficient due to several reasons. One of the main issues is that Revit and IESVE use different data formats for thermal and material properties. While Revit uses a range of parameters and values to define these properties, IESVE uses specific data models and algorithms to simulate and analyze them. Therefore, converting the data format of a Revit model before importing it into IESVE can be time-consuming and may result in data loss or errors. In addition, Revit's built-in library of thermal and material properties may not be comprehensive enough for detailed energy analysis and simulation in IESVE. This means that additional properties may need to be manually added or modified to match the requirements of the analysis. Moreover, the level of detail required for thermal and material properties may differ between Revit and IESVE, which can also be time-consuming.

On the other hand, when it comes to importing HVAC models from Revit to IESVE, the process may not be efficient for different reasons. First, the file formats used in Revit and IESVE are not the same, which requires converting the file format, leading to data loss or errors. Second, the object types used in Revit and IESVE are not always the same, requiring manual mapping that can be tedious and error prone. Third, HVAC models in Revit can be very complex and detailed, leading to a large file size and slow performance when importing into IESVE. Finally, the accuracy of data in the Revit model can impact the efficiency of importing HVAC models into IESVE, requiring manual checks and corrections.

In general, using Revit data for energy analysis and simulation in IESVE can save time. The speed and accuracy of the process may vary depending on the type of data being imported, but importing only geometry may be quicker and more precise. It's important to note that IESVE is not operable with thermal properties and HVAC models imported from Revit.

4.2 Renovation strategies for historic buildings

4.2.1 Energy efficiency in heritage historic buildings

The European Directive 2010/31/EU, also known as the Directive on Energy Efficiency in Buildings, mandates that buildings must be transformed into nearly zero energy (NZEB) structures by 2020. The challenge lies in retrofitting existing buildings, which make up most of the building stock. In Italy, this challenge is even more significant because many existing buildings are historic and subject to environmental and architectural constraints, as well as specific regulations for refurbishment. Retrofitting involves upgrading both the building shell and systems and is not covered by maintenance since it represents an adaptation for energy efficiency and sustainability.

4.2.1 Possible interventions in heritage historic buildings

It is important to note that interventions for historical buildings should be carefully planned and executed to preserve the building's historic character while still achieving energy efficiency goals. Major possible interventions considering IEA SHC Task 59 | EBC Annex 76 (Deep renovation of historic buildings towards lowest possible energy demand and CO₂ emission NZEB) is listed below:

Insulation: Insulating the walls, roof, and floors can significantly reduce the amount of heat lost through these surfaces. However, insulation materials should be chosen carefully to ensure that they are compatible with the historic building fabric and do not damage it.

Window and door replacement: Replacing old, single-pane windows and doors with modern, double-glazed units can help to reduce heat loss and improve the building's overall energy efficiency.

Lighting: Replacing incandescent bulbs with more energy-efficient lighting, such as LED or CFL bulbs, can reduce electricity usage and lower energy bills.

Heating and cooling systems: Upgrading the heating and cooling systems in historical buildings can improve energy efficiency. For example, replacing an old, inefficient boiler with a modern, high-efficiency model can reduce energy consumption and save money on heating bills.

Renewable energy sources: Historical buildings can also benefit from the installation of renewable energy sources, such as solar panels or wind turbines, which can help to reduce energy costs and carbon emissions.

Behavioral changes: Encouraging occupants to adopt energy-efficient behaviors, such as turning off lights when leaving a room and reducing heating and cooling settings, can also help to reduce energy consumption and improve the energy efficiency of historical buildings.

4.2.3 Case study: Interventions on Borgo Pirelli as a cultural heritage site

At the start of the renovation project, Borgo Pirelli was in poor condition with skewed walls and moisture damage affecting the wooden elements of its roof and floors. As a heritage building, there were limitations on external changes that could be made. Nevertheless, the primary aim of the renovation was to achieve an A-class energy rating, improve structural integrity, enhance thermal and acoustic insulation, and convert it into a luxurious residence with modern amenities.

To accomplish these goals, most of the renovation efforts were focused on upgrading thermal insulation of walls and roof. The building relied on traditional construction methods featuring bearing masonry and wooden floors, but without insulation in external walls, roof, and floors. Furthermore, the renovation involved implementing energy-efficient measures such as installing high-insulated windows. The building's structure was consolidated before the thermal and acoustic bridges were identified and addressed. All insulation was placed on the inner part of the external walls to preserve the building's original materials and architectural identity. The HVAC system used is not discussed in this thesis, only passive strategies.

To demonstrate the impact of these upgrades, charts were created comparing the building's energy needs before and after the renovation. The results revealed significant

energy savings, CO2 emission reductions, and overall cost reductions. This makes the renovated Borgo Pirelli a model of sustainable design and a beacon for future heritage building renovations.

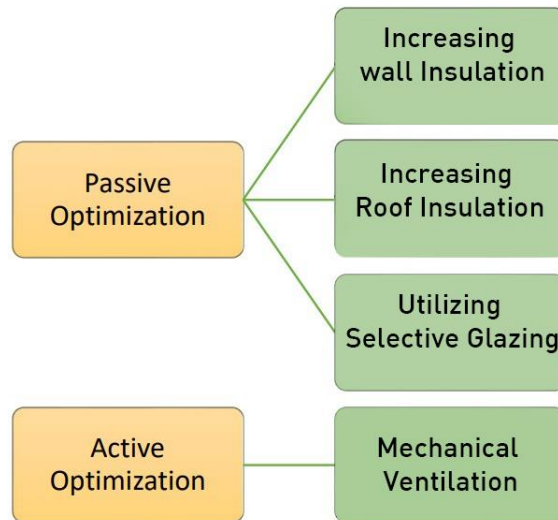


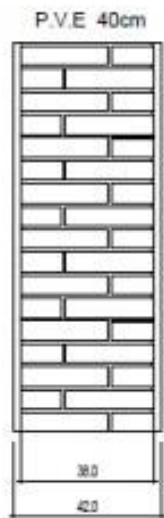
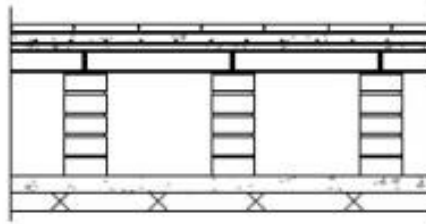
FIGURE 31- SUGGESTED RETROFITTING STRATEGIES FOR BORGO PIRELLI

4.2.3.1 Stratigraphy

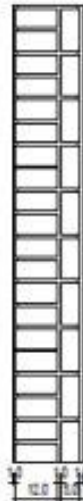
To begin, an initial presumption was made regarding the building materials used in the villa. Given its construction in 1921, it has been speculated that the vertical internal and external partitions were primarily made of clay bricks and did not have any insulation systems in place. Additionally, it is believed that the windows had a high level of thermal transmittance. The table below displays the composition of each component. It should be noted that the following information was gathered from multiple sources, including teacher guidelines and the website <https://webtool.building-typology.eu/#bd>, to verify these assumptions.

- 1- Pavimentazione
- 2- Massetto in cal con rete elettrosaldata 5cm
- 3- Tavelloni in Laterizio 6x25x50
- 4- Muricci a due teste in mattoni pieni
- 5- Getto di magrone per sottofondi 5cm
- 6- Terreno

Solaio Controtterra



P.V.I 02 20cm

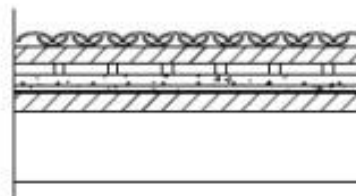


P.V.I 01 14 cm



- 1- Coppi
- 2- Tavolato in legno 5 cm
- 3- Listello di supporto
- 4- Massetto in cls con rette elettrosaldata 5 cm
- 5- Tavolato in Legno
- 6- Trave in Legno

Copertura Inclinata



Solaio Interpiano 40cm

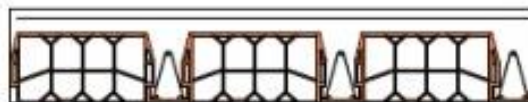


FIGURE 32- BORGO PIRELLI STRATIGRAPHY

4.2.3.1 IESVE assigned Project Construction: Baseline

The **external wall** has a thickness of 40,00 cm and a thermal transmittance equal to 1,51 W/m²K

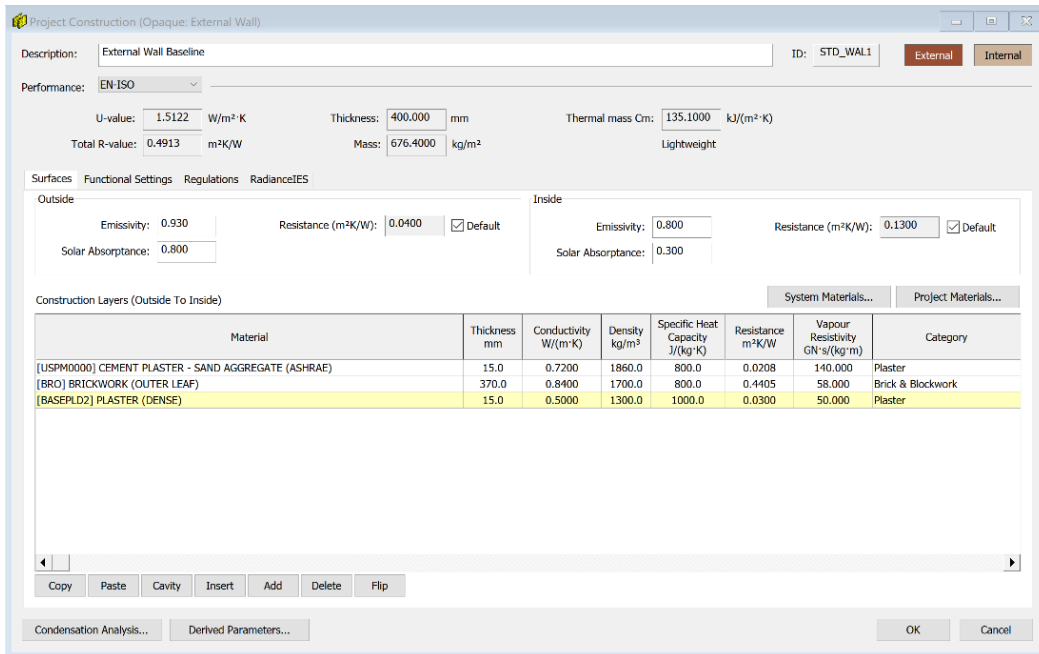


FIGURE 33: EXTERNAL WALL DEFINITION IN IESVE

Internal Wall: The internal wall has a thickness of 18,00 cm and a thermal transmittance equal to 1,33 W/m²K

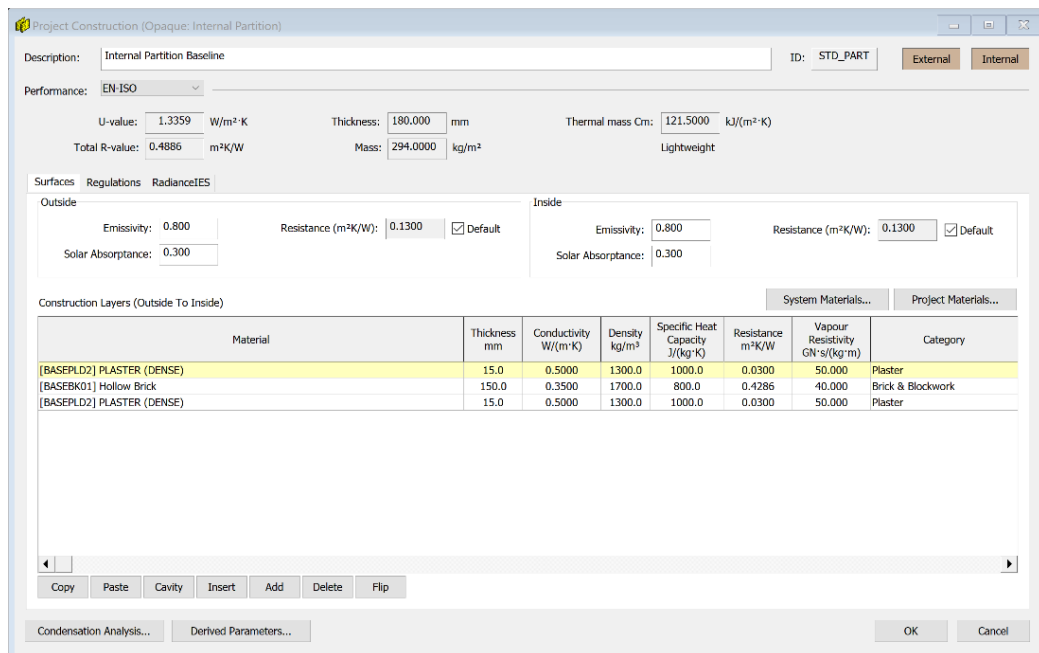


FIGURE 34: INTERNAL PARTITION DEFINITION IN IESVE

Internal Floor: The Internal Floor has a thickness of 35,00 cm and a thermal transmittance equal to 1,21 W/m²K.

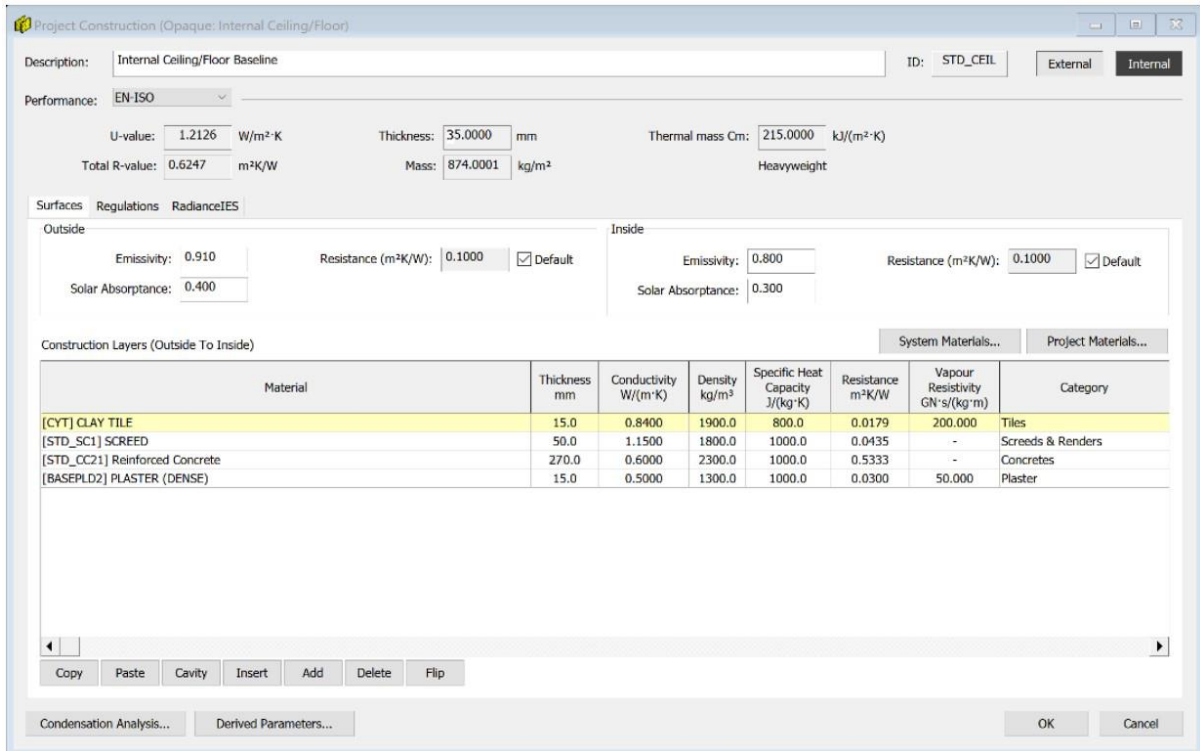


FIGURE 35: INTERNAL FLOOR/CEILING DEFINITION IN IESVE

Pitched roof: The Roof has a thickness of 35 cm and a thermal transmittance equal to 0.93 W/m²K.

The effects of the pitched roof and the attic have been considered as a insulation layer with thermal resistivity equal to 0.3 m².K/W which was acquired from the table below from the standard.

Table 9 — Thermal resistance of roof spaces

Characteristics of roof		R_u m ² ·K/W
1	Tiled roof with no felt, boards or similar	0,06
2	Sheeted roof, or tiled roof with felt or boards or similar under the tiles	0,2
3	As 2 (above) but with aluminium cladding or other low emissivity surface at underside of roof	0,3
4	Roof lined with boards and felt	0,3

NOTE The values in this table include the thermal resistance of the ventilated space and the thermal resistance of the (pitched) roof construction. They do not include the external surface resistance, R_{se} .

FIGURE 6: THERMAL RESISTANCE OF ROOF SPACES

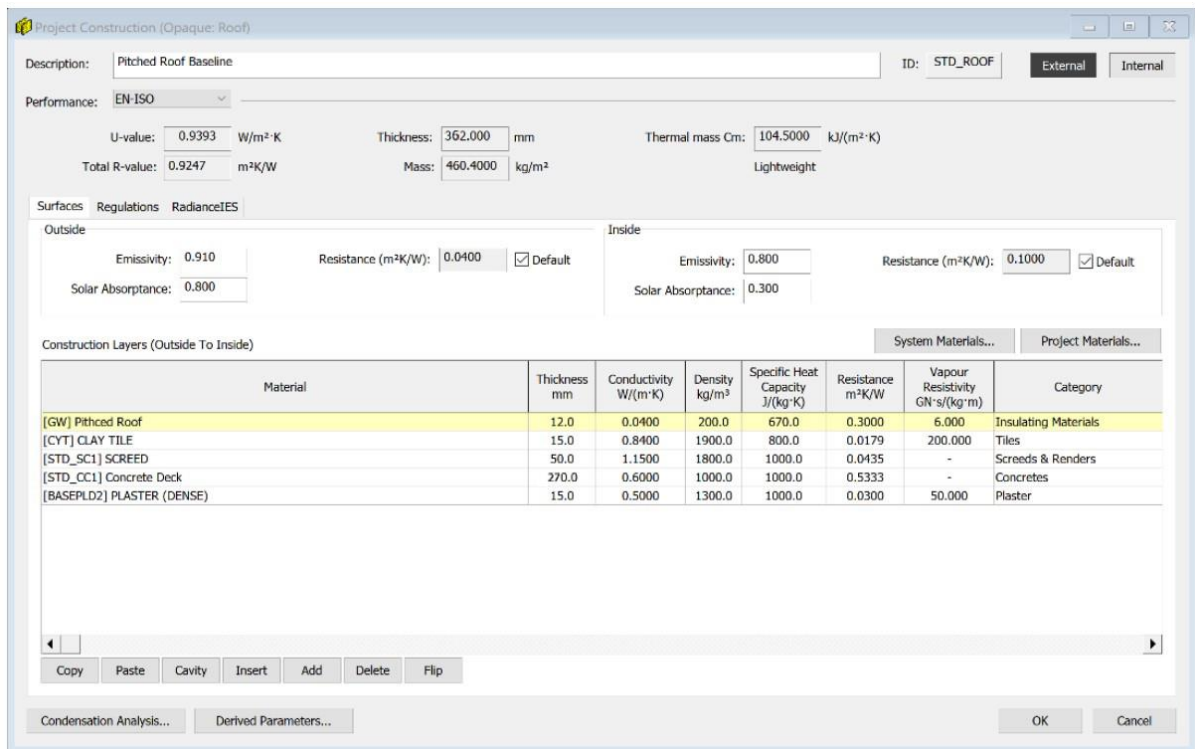


FIGURE 36: PITCHED ROOF DEFINITION IN IESVE

Flat Roof: The Roof has a thickness of 35.5 cm and a thermal transmittance equal to 1,3 W/m²K.

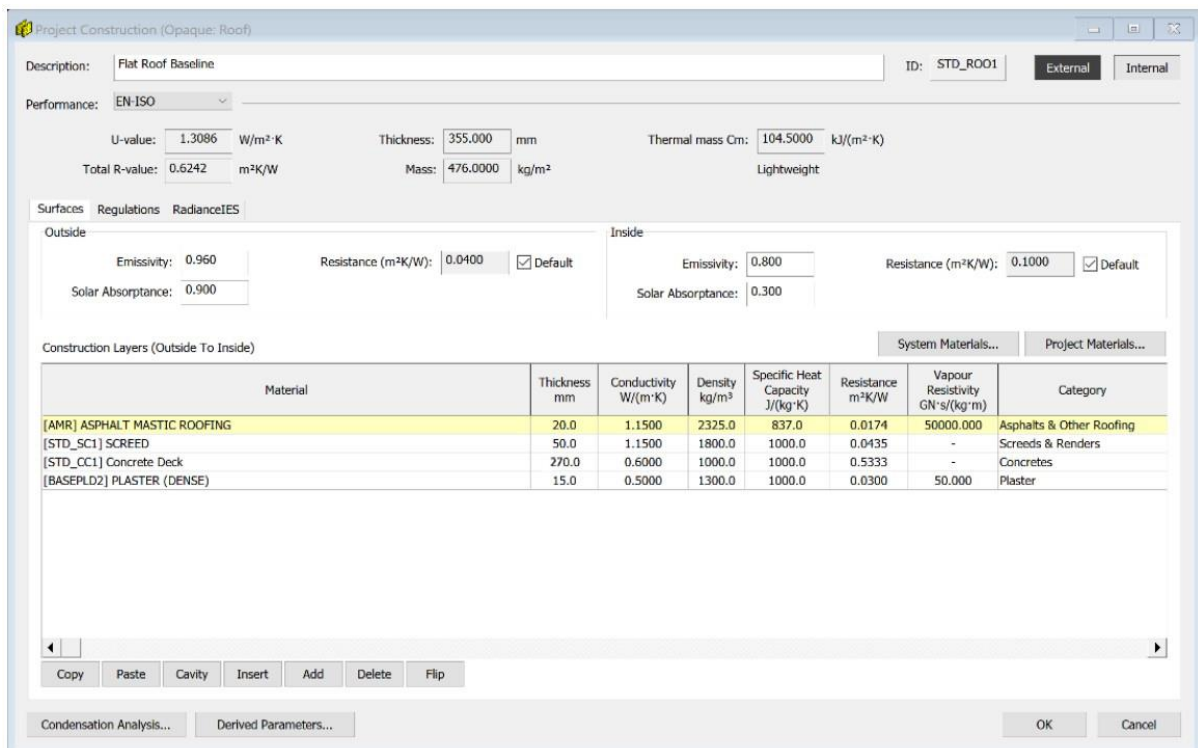


FIGURE37: FLAT ROOF DEFINITION IN IESVE

Ground Exposed Floor: The Ground Exposed Floor has a thickness of 35 cm and a thermal transmittance equal to 1,26 W/m²K

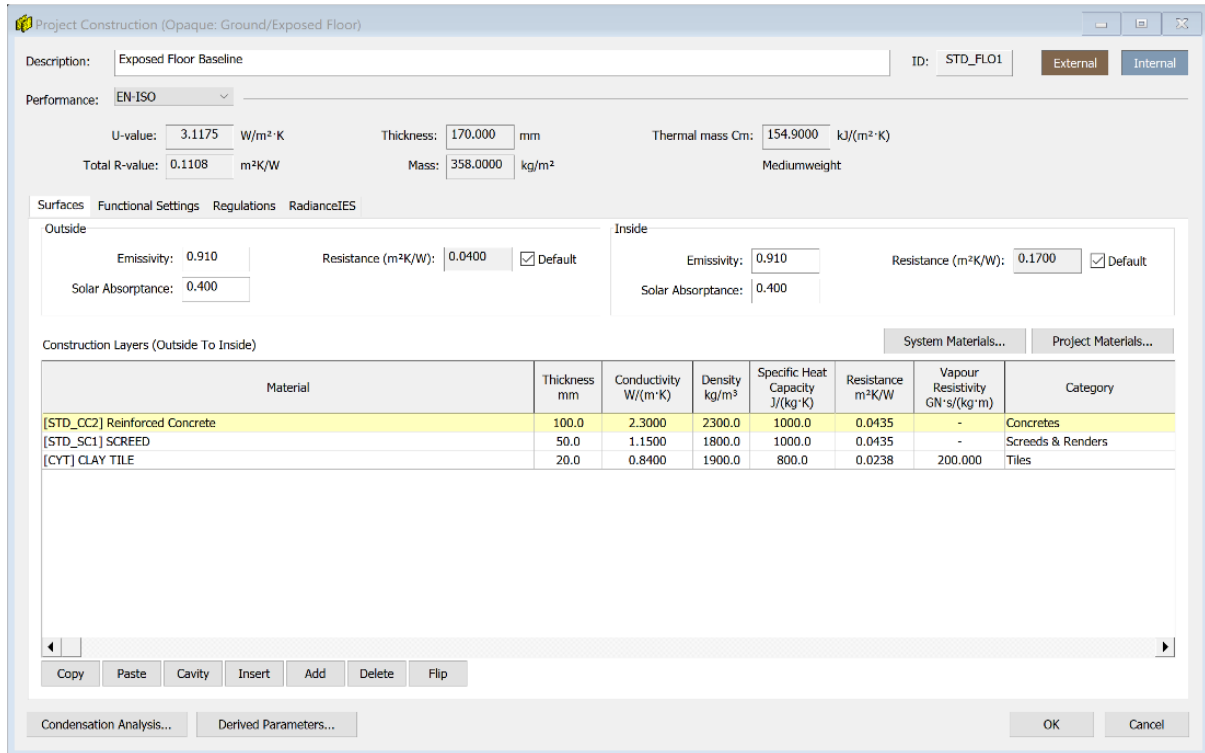


FIGURE 38: GROUND EXPOSED FLOOR DEFINITION IN IESVE

Window: The window has a thermal transmittance of 5.03 W/m²K

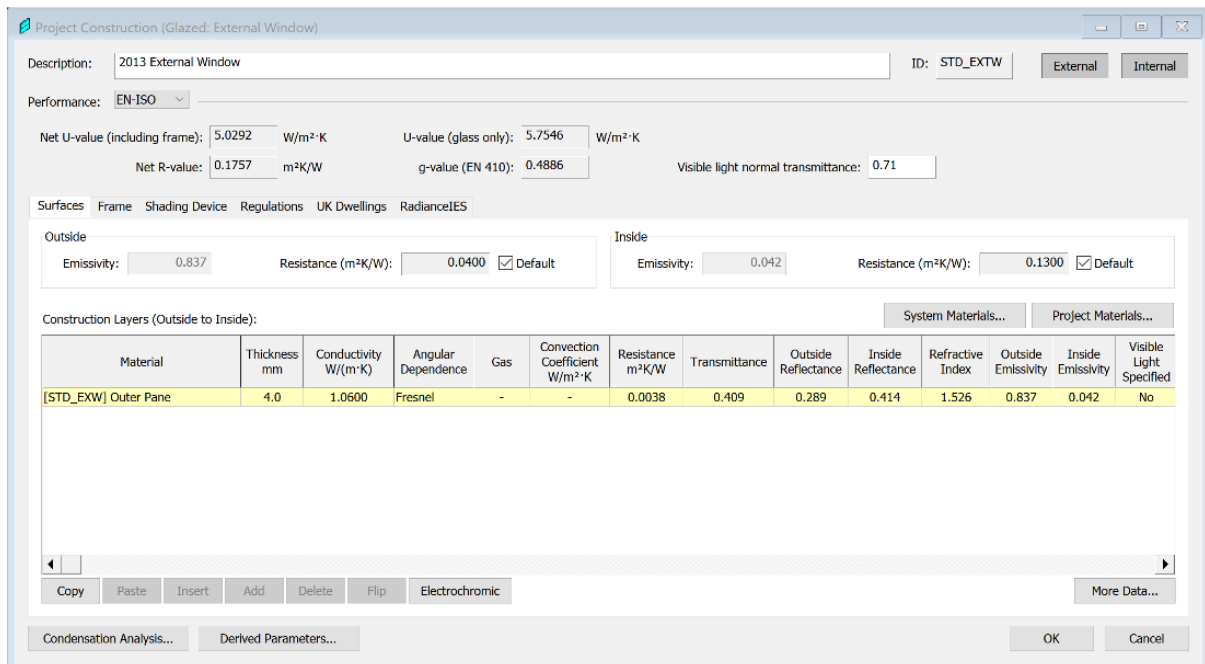
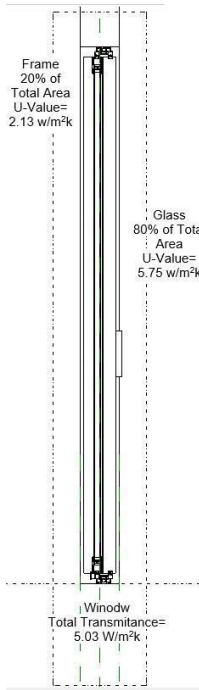


FIGURE 39: GLAZING DEFINITION IN IESVE



The window has been considered:

- 20% frame: U-value: 2.13 W/m²K

- 80% glass U-value: 5.75 W/m²K

FIGURE 40: GLAZING U-VALUE BASED ON THE PART

Heating and cooling hours

Based on the outdoor dry bulb temperatures analyzed above, the following charts show the percentage of hours in which the building needs cooling, heating or the internal temperature falls in the comfort ranges computed.

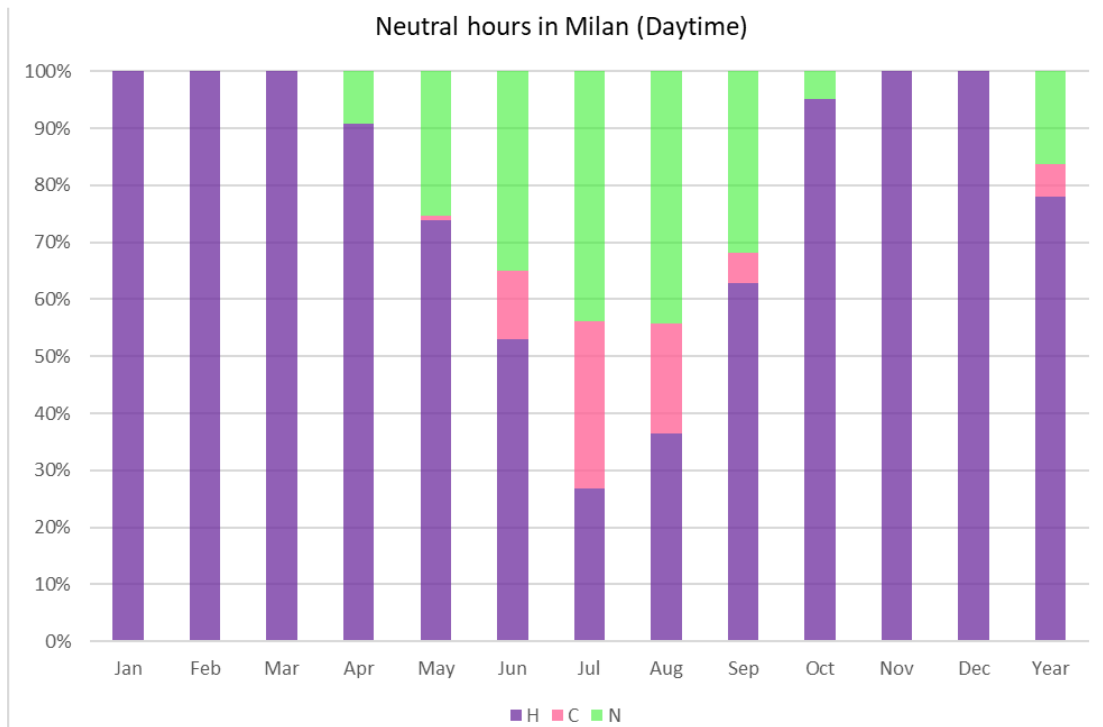


CHART 7 COOLING/HEATING HOURS-DAYTIME

4.2.3.1 IESVE Optimization step 1

First step of optimization: applying the insulation on walls for improving the envelope conduction performance

Aerogel: High Performance Insulation for Building Envelopes

Aerogel is a nanostructured, open porous solid made from sol-gel technology. These ultra-light materials are fragile and expanded polystyrene to the touch.

Why Choose Aerogel Wall Insulation?

Aerogel has very low thermal conductivity, which means that it is very good at preventing the transfer of heat. This makes it an ideal material for thermal insulation applications, particularly in buildings that require high levels of insulation to maintain comfortable indoor temperatures and reduce energy costs.

Aerogel can be used in a variety of ways for building insulation. It can be added as an insulation layer to the interior or exterior walls, roof, and floor of the building. Aerogel insulation can also be used to insulate pipes and other building systems that require thermal insulation. In addition to its thermal insulation properties, aerogel is also very lightweight and durable. It is resistant to moisture, fire, and chemicals, making it an ideal material for use in building insulation. Overall, aerogel is a highly effective and versatile material that can significantly improve the energy efficiency of existing buildings.



Product Properties and Sustainability

Thicknesses*	0.2 in (5 mm) 0.4 in (10 mm)
Width*	58 in (1,475 mm)
Thermal Conductivity ASTM C 518 (Mean Temp. 75°F) EN 12667 (Mean Temp. 10°C)	0.101 BTU-in/hr-ft ² -°F 14 mW/m-K
Color	Gray
Compressive Strength ASTM C 165	8 psi stress at 10% compression
Fire Performance ASTM E 84	Class A
Water Vapor Transmission ASTM E 96	33 Perms
Hydrophobic	Yes
Embodied Energy	53 MJ/kg
Embodied CO₂	4.2 kg of CO ₂ /kg

The new wall definition in IESVE:

Project Construction (Opaque: External Wall)

Description: External Wall Insulated 10mm ID: STD_WAL3 External Internal

Performance: EN-ISO

U-value: 0.3642 W/m²·K Thickness: 510.000 mm Thermal mass Cm: 18.8100 kJ/(m²·K)
 Total R-value: 2.5761 m²/W Mass: 701.9000 kg/m² Very lightweight

Surfaces Functional Settings Regulations RadianceES

Outside Emissivity: 0.930 Resistance (m²K/W): 0.0400 Default
 Solar Absorptance: 0.800

Inside Emissivity: 0.800 Resistance (m²K/W): 0.1300 Default
 Solar Absorptance: 0.300

Construction Layers (Outside To Inside) System Materials... Project Materials...

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m ³	Specific Heat Capacity J/(kg·K)	Resistance m ² K/W	Vapour Resistivity GN·s/(kg·m)	Category
[USPM0000] CEMENT PLASTER - SAND AGGREGATE (ASHRAE)	15.0	0.7200	1860.0	800.0	0.0208	140.000	Plaster
[BRO] BRICKWORK (OUTER LEAF)	370.0	0.8400	1700.0	800.0	0.4405	58.000	Brick & Blockwork
[BASEPLD2] PLASTER (DENSE)	15.0	0.5000	1300.0	1000.0	0.0300	50.000	Plaster
Cavity	10.0	-	-	-	0.1800	-	-
[STD_PHF] Insulation	10.0	0.0720	40.0	836.0	1.7857	-	Insulating Materials
[GPB] GYPSUM PLASTERBOARD	25.0	0.2100	900.0	836.0	0.1190	45.000	Plaster

Copy Paste Cavity Insert Add Delete Flip

Condensation Analysis... Derived Parameters... OK Cancel

FIGURE 41: WALL INITIAL DEFINITION IN IESVE

4.2.3.2 IESVE Optimization step 2

The second step of optimization: applying the insulation on roof for improving the roof conduction performance

The new Roof definition in IESVE:

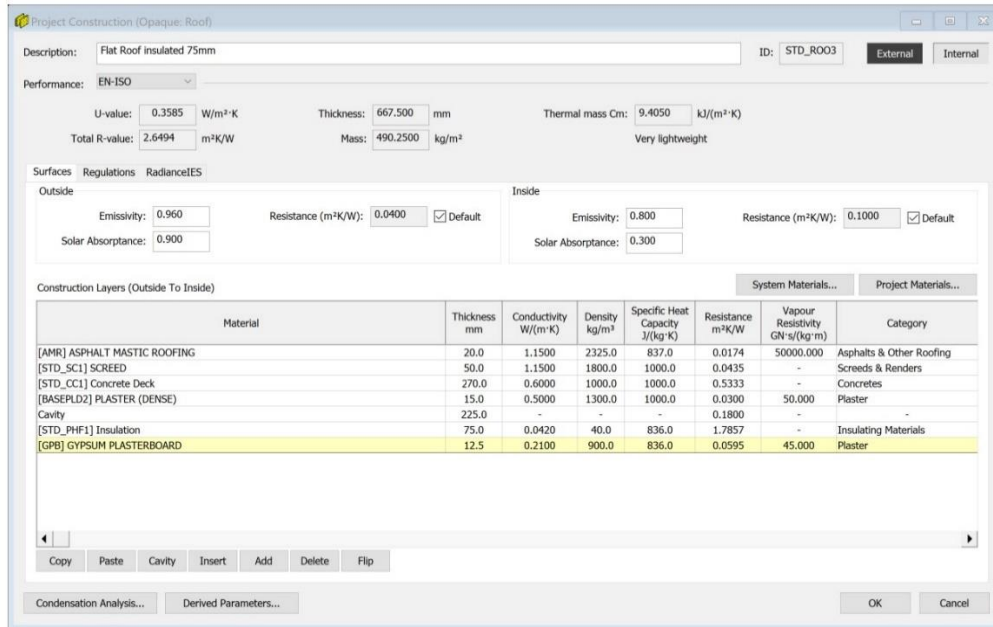


FIGURE 42: NEW ROOF DEFINITION IN IESVE

4.2.3.3 IESVE Optimization step 3

Third step of optimization: Changing the glazing without changing the frame

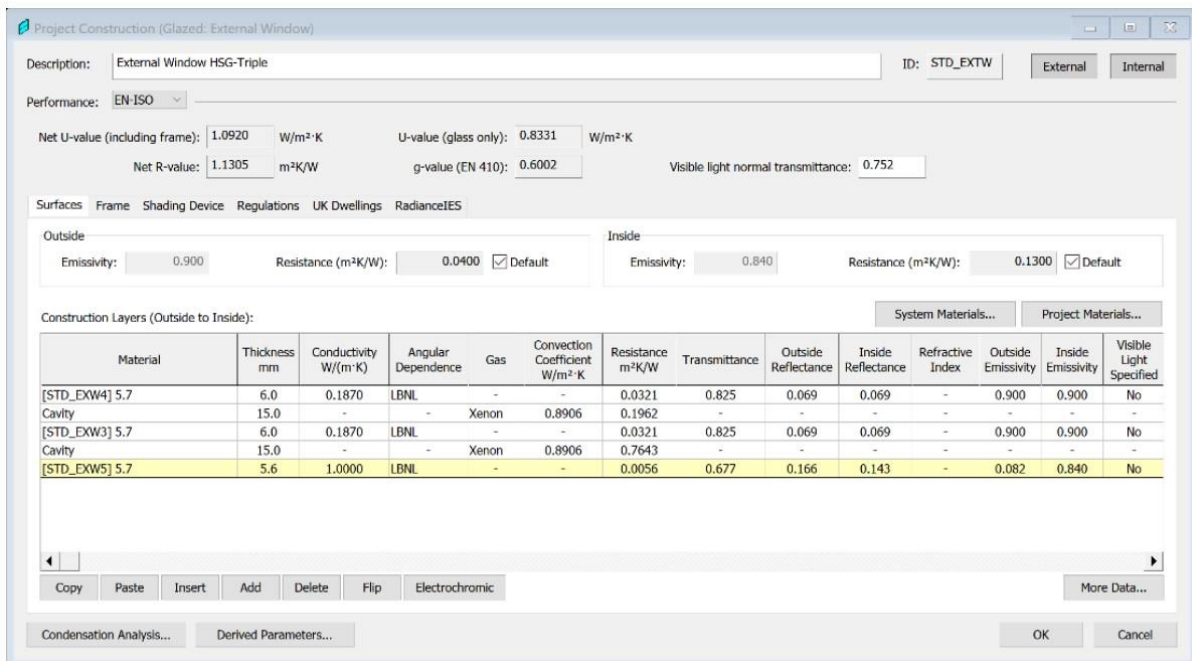


FIGURE 43: NEW GLAZING DEFINITION IN IESVE

HEATING AND COOLING HOURS

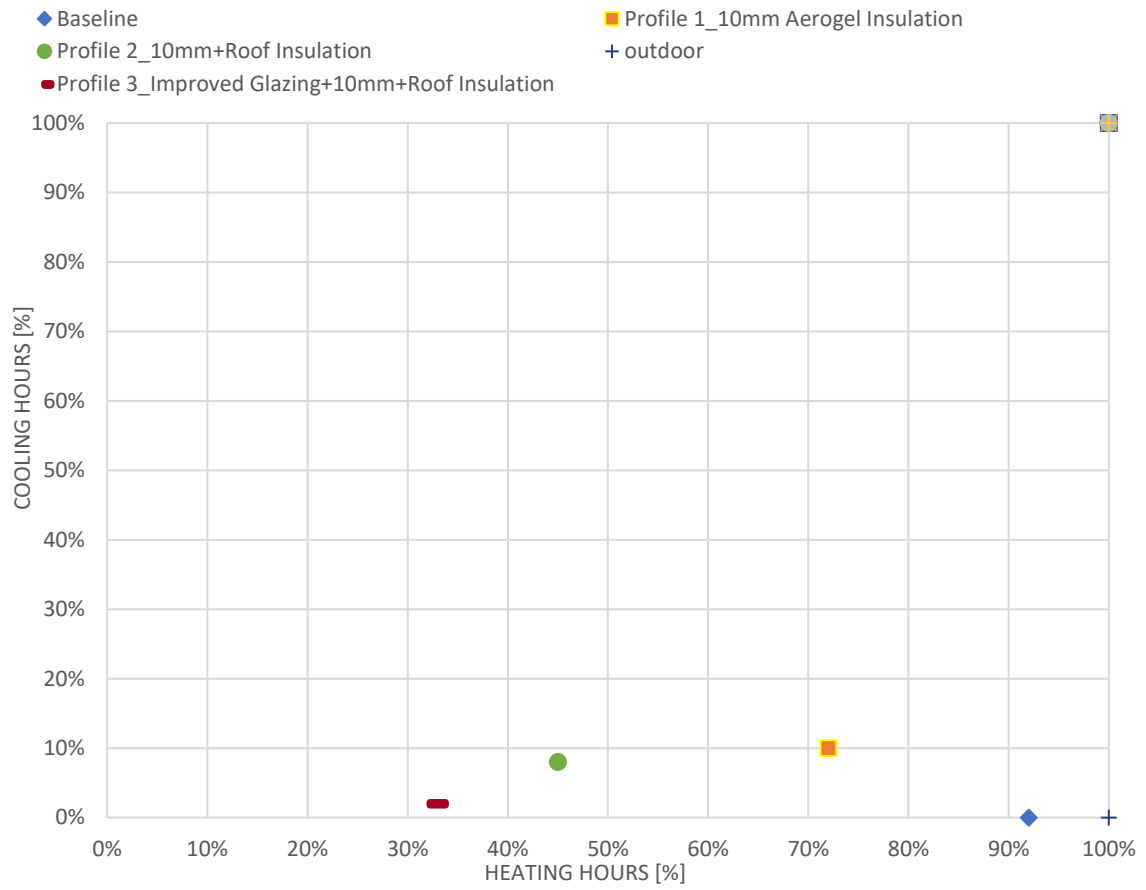


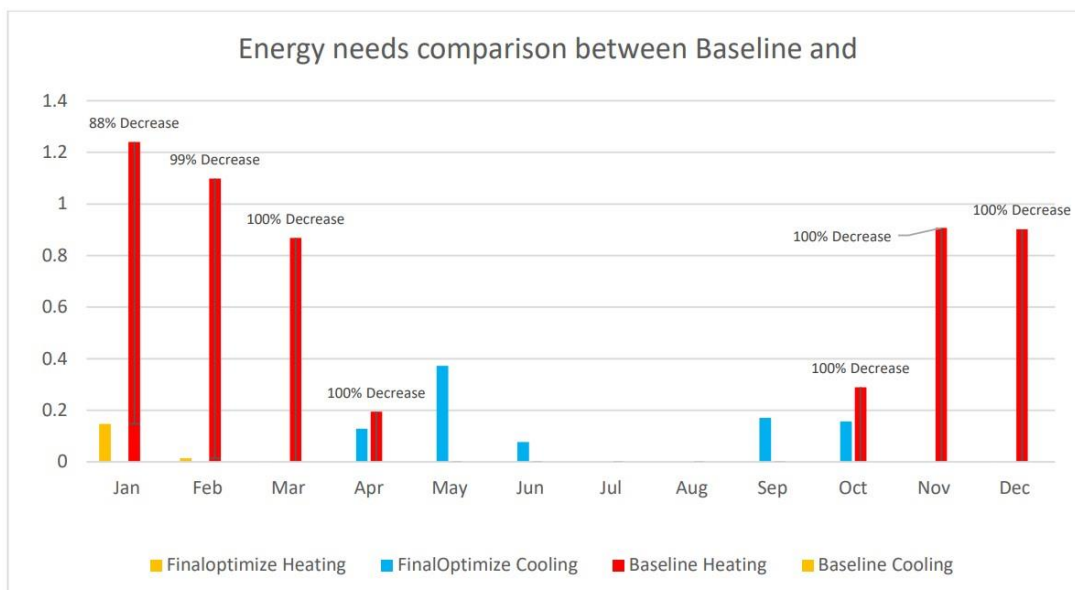
FIGURE 41: HEATING AND COOLING HOURS FOR DIFFERENT OPTIONS

Conclusion

In this thesis, the researcher analyzed the interoperability between Revit and IESVE and explored possible interventions for the cultural heritage building Borgo Pirelli. The aim was to improve the building's efficiency, and three interventions were examined. The results showed a significant decrease in heating hours, but a moderate increase in cooling hours in the studied zone. Due to technical difficulties, data from another space was used to assess the energy savings from baseline to the current optimized project.

The findings indicate that the interventions led to a reduction in heating energy requirements, but a slight increase in cooling needs. Despite this, the overall impact of the interventions was positive, as the decrease in heating hours outweighed the increase in cooling hours. The arduous process undertaken in analyzing and optimizing the building's energy performance resulted in notable improvements in reducing heating hours and moderately increasing cooling hours in the studied zone.

However, it is important to note that due to technical difficulties, data from another space was used in one section of the analysis. Nonetheless, this data allowed for an assessment of the energy savings achieved in the optimized project compared to the baseline. The results suggest that the interventions were effective in improving the building's energy efficiency, with a reduction in heating energy needs being the most significant outcome.



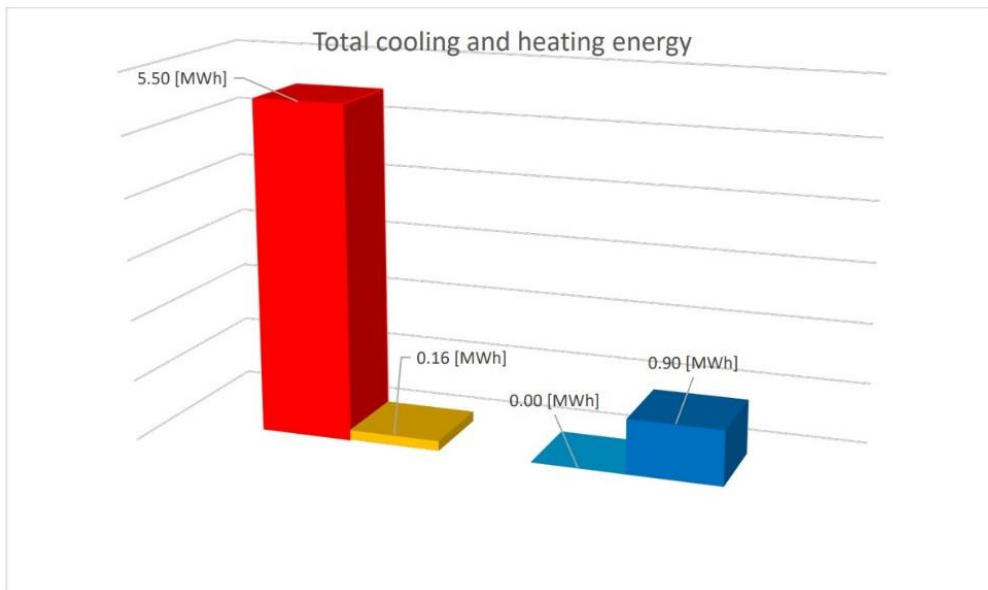


FIGURE 42: ENERGY NEEDS COMPARISON BETWEEN THE BASELINE AND FINAL STRATEGY

In conclusion, this thesis demonstrates the potential of using interoperability between Revit and IESVE for optimizing the energy performance of cultural heritage buildings such as Borgo Pirelli. Despite a slight increase in cooling needs, the overall impact of the interventions was positive, with notable reductions in heating hours and improvements in energy efficiency. Further research and optimization efforts could be undertaken to fine-tune the interventions and achieve even greater energy savings in the future.

this thesis, the interoperability of Revit and IESVE and possible interventions on cultural heritage building Borgo Pirelli was analyzed. To improve the efficiency of the one the building 3 interventions have been examined and a huge difference in heating hours while a rise in the cooling hours was seen. At the end in the following, all the arduous process that was undertaken the heating hours reduced significantly while increasing moderately the cooling hours in the studied zone. Due to some technical difficulty, the resultant result of another space will be used in this section for seeing how much energy was saved from baseline to the current optimized project.

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