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PANELIZATION DESIGN TOOL

PARAMETRIC-BIM BASED TOOL FOR THE RENOVATION OF A MULTI STOREY RESIDENTIAL BUILDING

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ABSTRACT

The **construction sector** *is today one of the main pollutants* on the planet, both in terms of *energy* and *resource* consumption. The growth trend of the **world population** is still positive with an estimated increase in the urban population, which is where the greatest consumption and waste are concentrated. The situation is therefore not sustainable in the long term and thus the need arises for major redevelopment interventions of the **building heritage**, which at the European level, is *highly dated* and *inefficient*.

The approaches to **retrofit operations**, however, often take place with *traditional techniques* that can lead to non-optimal management of resources, times and costs. Also, since these types of interventions are often *fragmented* and *dispersive*, these requalifications often fail to achieve the objectives set and frequently do not consider factors beyond the third dimension (3D), that is, of simple geometric modelling. A new type of approach is thus necessary, which draws from the **Modern Method of Construction (MMC)** that set of information and procedures necessary to revive a sector that very *slowly incorporates technological progress* and whose founding logics have remained substantially unchanged from the mid-twentieth century. The advantages brought about by the joint use of **Design for Manufacturing and Assembly (DfMA)** and **Building Information Modeling (BIM)** can in fact lead to significant improvements in terms of *costs*, *time* and *energy consumption* but at the same time increasing *quality* and *security*.

We are therefore talking about a **Decision Support System (DSS)** able to guide all the figures involved in the *early-design stage*, which considers the phases of: Geometric Modeling (*3D*), Time Planning (*4D*), Estimation and Cost Evaluation (*5D*), Performance Analysis (*6D*), Operational Management of Building (*7D*). The approach to these issues must take place with a *holistic* and *multiparametric method*, for an evaluation that truly takes into account all the variables involved and the reciprocal interactions between them.

Il **settore delle costruzioni** *è oggi uno dei principali inquinanti* del pianeta, sia in termini di consumo di energia che di risorse. Il trend di crescita della **popolazione mondiale** è tuttora positivo con un aumento stimato della popolazione urbana, dove si concentrano i maggiori consumi e sprechi. La situazione non è quindi sostenibile nel lungo periodo e si pone quindi la necessità di importanti interventi di riqualificazione del **patrimonio edilizio**, che a livello europeo, è molto *datato e inefficiente*.

Gli approcci alle **operazioni di retrofit**, però, spesso avvengono con tecniche tradizionali che possono portare ad una gestione non ottimale di risorse, tempi e costi. Inoltre, poiché questi tipi di interventi sono spesso *frammentati e dispersivi*, queste riqualificazioni spesso non riescono a raggiungere gli obiettivi prefissati e spesso non considerano fattori oltre la terza dimensione (3D), cioè di semplice modellazione geometrica. È quindi necessario un nuovo tipo di approccio, che trae dai **Modern Method of Construction (MMC)** quell'insieme di informazioni e procedure necessarie a rilanciare un settore che *ingloba molto lentamente il progresso tecnologico* e le cui logiche fondanti sono rimaste sostanzialmente invariate dalla metà del XXesimo secolo. I vantaggi portati dall'utilizzo congiunto di **Design for Manufacturing and Assembly (DfMA)** e **Building Information Modeling (BIM)** possono infatti portare a significativi miglioramenti in termini di *costi, tempi e consumi energetici* ma allo stesso tempo aumentando *qualità* e *sicurezza*.

Si tratta quindi di un **Decision Support System (DSS)** in grado di guidare tutte le figure coinvolte nella fase di *early design*, che considera le operazioni di: *Geometric Modeling* (3D), *Time Planning* (4D), *Estimation* and *Cost Evaluation* (5D), *Analisi delle prestazioni* (6D), *Gestione operativa dell'edificio* (7D). L'approccio a queste tematiche deve avvenire con un *metodo olistico* e *multi-parametrico*, per una valutazione che tenga veramente conto di tutte le variabili in gioco e delle reciproche interazioni tra loro.

Summary

1. INTRODUCTION

1.1 Foreword

Only after a careful analysis of the State of the Art, we did realize the **impact** that the construction sector has in terms of **energy** and **resource consumption** on the World Environment. Citing some numbers that we will recall below, buildings account for about 40% of final annual energy consumption, two-thirds of which are attributable to the residential sector and for as much as 30% of total CO_2 emissions. Even this trend is even destined to worsen if not appropriately and promptly mitigated in the immediate future. The **human population** is destined to grow dramatically, with a substantial increase in the urban areas, which are responsible for as much as 70% of total carbon emissions.

Moreover, the European **building heritage** is very **dated**, with **energy performances** of the envelope well **below** the **current standards** of thermal transmittance. This causes strong losses of heat to the external environment and therefore an unsustainable waste of energy for heating living spaces.

The current trend of the **building market** is, however, to focus on the theme of building redevelopments, rather than on newly built interventions, with the **retrofit** market that has had continuous and approximately constant **growth** since the end of the 90s. In fact, at present, it is the real economic stabilizer of the construction sector.

Moreover, it was heavily financed at the Italian state level with **economic incentives**, aimed at improving the anti-seismic performances (*Sisma Bonus*), maintenance of the facades (*Bonus Facades*) and energy efficiency (*Ecobonus*). The confirmation of the old forms of financing and the adoption of new economic measures to support building renovation (including the so-called *Super bonus 110%*), clearly indicate that this trend will be confirmed in the next few years with great probability.

It is in this context that the **Modern Method of Construction** (MMC) has been developed, which seek to combine the new processes of **Design for Manufacturing and Assembly** (DfMA) together with the increasingly consolidated **Building Information Modeling** (BIM) modelling technologies. Therefore, starting from the principles of *purpose*, *quality*, *timing*, *costs*, *risk*, *work* and *degree of invasiveness*, an attempt has been made to investigate the manner and degree of influence that these years have on the design choice. Specifically, the equation

$$Q\ (quality) \times T\ (time) = S\ (objective) \times C\ (cost)$$

allow us to investigate the relationship between these quantities and how an **innovative approach** to the world of construction can lead to significant advantages. These pros in favour of the new systems are to be found first in the **modernization of the building**, which gives a new opportunity for improvement in terms of architectural quality and technical performance (energy, etc.). **Reverse Engineering** (RE) and **Digital Workflows** tools also participate in this process; while RE means the design and production of parts based on a digital model obtained from a physical object (the building in fact), the digital information flow allows to maintain a strong accuracy and control over the entire process. All this leads to an improvement in **On-site productivity**, with manufacturers able to reach high levels especially in the assembly phase, which **reduces** production **times** also avoiding non-production times, preparation work, misaligned deliveries, etc. Speaking of the **economic advantages**, reducing intervention times as well as improving overall quality leads to higher average *Return on Investment* (ROI) and *Return on Equity* (ROE) values, an index of the value of the intervention carried out. Finally, accurate and planned **management** from the very early stages of the design allows optimizing the overall performance of a building - from production to decommissioning - in terms of resources to materials, thus avoiding waste especially in the very early and final stages of the life cycle.

From what we have just seen, the need and the opportunity to carry out important building renewal interventions emerges, which we will try to seize as shown below.

1.2 Goal and Scope

The concepts just mentioned are part of the *European research call* **Building Information Modeling for Energy-Efficient Buildings** (**BIM4EEB**) which aims at an *energy requalification of the European housing stock* with the help of new digital technologies and management of the flow balances of energy. From the three case studies - all European - it was decided to take *Monza* as a model for geographic proximity and design techniques.

The **project**, therefore, started with the definition of a path that led us to expand the complexity of the reference **geometric model** more and more, passing from a 2D facade to a 3D model up to a *BIM model*, from which we have taken geometries and information. These data were taken through a process of exporting **from BIM to the parametric environment** with methodologies still being perfected, but which act as a bridge between two of the most used design environments.

The import of data does not take place only from BIM, but also - and above all - through an **Excel** calculation file that contains *design constraints* (in general **input**) and *analysis results* (**output**) of all the geometric modelling and calculation that follows. This allows in fact to have an *interface that can be used by everyone*, without the tool being limited in some way.

Having clarified the geometries and design constraints, we then move on to the definition of the **stratigraphies** to comply with the *regulations in force* on energy saving. This process generally takes place through the addition of *external insulation systems*, in different thicknesses and materials depending on the specificity of the chosen solution. The actual **panelling** part then follows, where with the available data and geometries, different patterns of elements are created according to the solutions considered acceptable. A strong advantage, especially in this field, was offered by the use of **parametric modelling** software, which allowed us to be able to probe various options with a relatively low modelling effort. **A catalogue** of the elements was therefore created as an information label, to facilitate the information part of the design process.

The intermediate phase of this development is occupied by the **analyzes** carried out in terms of: Global Average **Heat Exchange** Coefficient H'_T, number of panel **Anchors**, management and estimation of **Time** and **Cost**, **Management** in terms of the environmental impact of the various stages of the process (from production to demolition) according to the procedure suggested by the Life Cycle Assessment (LCA). We would certainly have the opportunity to do it later, but we must emphasize that the degrees of depth of each analysis are defined *according to the general objective*, that is, the overall evaluation according to a holistic method.

Finally, we move on to the **results management** phase, which must be *as open and usable as possible* by all. Three methods were analyzed. The **first** concerns data management through graphs and explanatory images according to the *Design Optioneering* (DO) method, in which it is possible to select each solution individually and display the corresponding values for the parameters analyzed; it exploits the potential offered by **Design Explorer** tool by CORE Studio | Thornton Tomasetti. The **second** way studied concerns the possibility of visualizing the data through summary **Spider Diagrams**, where on each segment a quantity among those listed above is represented, re-parameterized based on a specific domain calibrated according to advanced estimates; each value is then assigned a score on a scale ranging from 1 to 4 and therefore overall evaluations can be made. The **last** method of visualization of the results, perhaps concerns the design field in the strict sense, as it aims to **export** all the panels (geometries) and catalogues (information) obtained in a parametric environment **to** the **BIM** environment; it will therefore be possible to interact with the BIM model to extrapolate valuable data.

Concluding our proposal, it, therefore, aims at the creation of a **Decision Support System** (DSS), which can guide the design choices in the **early-stage design** phase. After all, the adoption of the BIM4EEB concepts led to the application of the **Building Information Model Management System** (BIMMS) concepts, which is a collaborative work platform in a building renovation project capable of storing and sharing data among users. In this theoretical framework the aspects of **Geometric Modeling** (3D), **Time Planning** (4D), **Estimation** and **Cost Evaluation** (5D), **Performance Analysis** (6D), **Operational Management of Building** (7D) will be analyzed. The results thus obtained will be collected and presented jointly, for the management of the process that is as holistic and open source as possible by all those involved.

2. STATE OF THE ART

CHAPTER'S SUMMARY:

In this first chapter we try to relate the impact that the construction sector has on the **environment** and how **Modern Method of Costructions** (MMC) are trying to respond to this and other problems to innovate a sector that is known to be very slow in accepting new technologies. **Design for Manufacturing and Assembly** (DfMA) is an option, especially now that **BIM** technologies are spreading widely.

The following chapter 3.1 Global overview was developed also using data and statics collected and processed within the Project Report [1] of the "Progettazione di Sottosistemi e Componenti Edilizi - PSCE" course hold by Prof. Eng. Andrea G. Mainini.

We, therefore, thank all the SCAFADE design team - of which we are members - for their kind concession.

2.1 Global overview

In order to identify the possible problems to be solved and the opportunities offered by the building market, an introductory approach brings a series of considerations and data extrapolated and reworked mainly from the documentation found [2] [3]. This chapter, therefore, aims to lay the foundations useful for the development of an idea that can meet real needs and well-integrated into the current construction market.

Impact of the residential sector on the environment

With a consumption Final of 458 Mtoe In EU territories in 2016, **buildings account for 41% of the use of final annual energy, two-thirds of which are attributable to the residential sector** [4]. CO_2 emissions related to building energy - which in 2016 amounted to 33% of total [5] - are really increased in recent years (after the flattening between 2013 and 2016), reaching 10 $GtCO_2$ and the highest level ever recorded [6] :

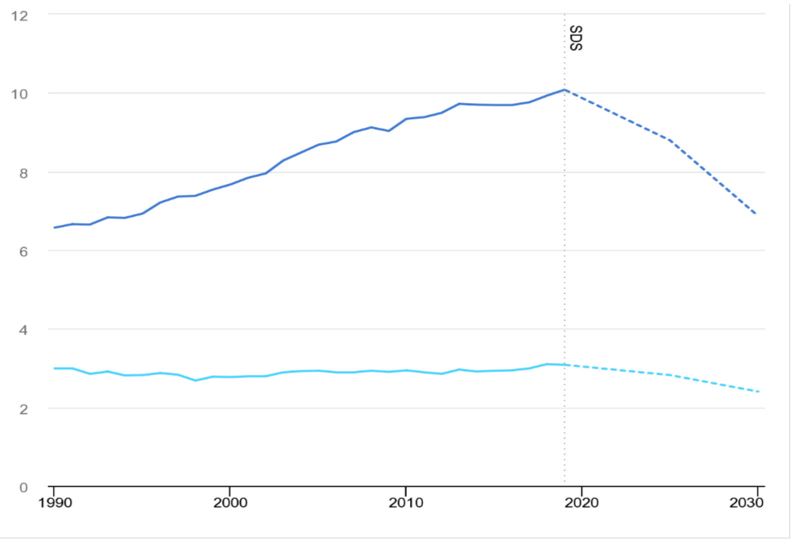


Figure 2.1_ CO2 emissions in the building sector in the sustainable development scenario, 2000-2030

Although these considerations have already been put forward some decade ago [7] and although some steps in this direction have already been taken, to date **the residential sector has the greatest potential for untapped mitigation** [8] :

Around 225 Mtoe of energy savings in 2017 compared to 2000 (i.e. 20% of final energy consumption). Without these savings, the final energy consumption would have been 20% higher in 2017. Most of these savings come from households (50%), 30% from industry, 17% from transport and 4% from services.

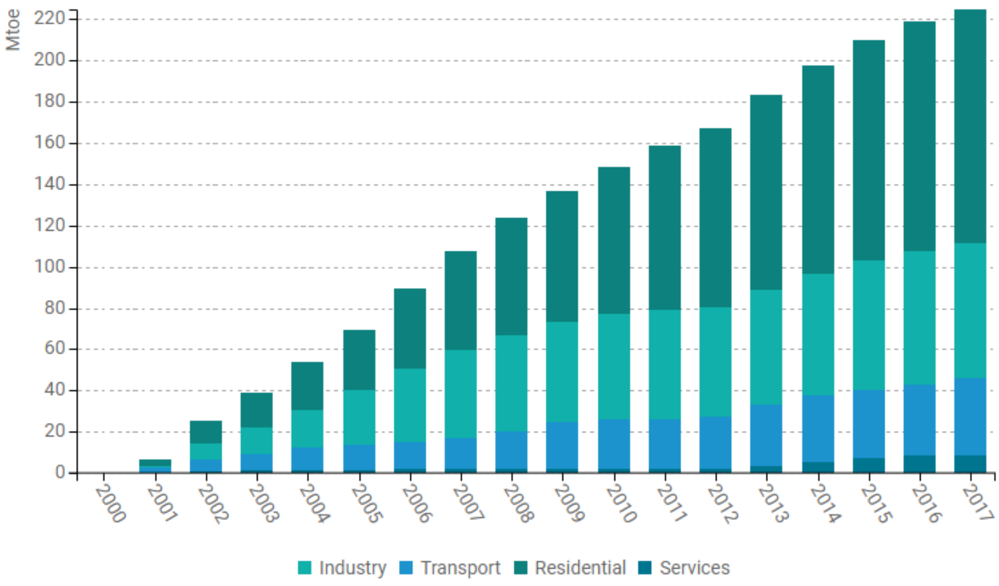


Figure 2.2_ Energy savings in the EU. Credits: ODYSSEE_MURE

Reconfiguration of the construction market

The Italian construction market in the decade between 2008 and 2018 has changed profoundly, just think that the existing asset maintenance activity represented 56% of the value of the sector, while in 2018 73.6%. This is due on the one hand to the crisis of new construction, which lost 47.8% of investments, and, on the other, to the very rapid growth of the redevelopment activity of the existing one, which grew by 13.2%, dragged up by the residential sector (+26.2%). This growth in redevelopment activity can be traced back to a number of concurrent causes which, as reported in the Recovery and [22] *Energy Redevelopment* of the building stock mentioned above, are:

- the process of ageing the building stock that, over time, determines necessary interventions to maintain the functional standards of goods;
- changing the quality standards of living;
- the significant changes of ownership that accelerate interventions;
- technological and regulatory innovation processes that drive substitution and/or adaptation interventions.

Not to mention that since 1998 an important role has been played by the tax incentives from which building recovery and energy redevelopment have benefited.

Renovation in the residential building sector

Analyzing the dynamics of investments in residential construction from 1982 and updated to 2018, it is clear the cyclical **role played by the extraordinary maintenance activity and the progressive crisis of new construction**. Driven by the ageing of the building stock conditioned by the historical construction eras of our country, the redevelopment activity experienced the first phase of growth in the 90s that continued to the present day and therefore in times of crisis: it is therefore evident how the losses of the new construction with the passage of time leave room for the renewal market [2].

According to the World Business Council for Sustainable Development (WBCSD), **more than half of Europe's building stock is dated between 1925 and 1975**, for a total of about 80 million buildings. Focusing on the situation of the Italian built, we can see how the data are absolutely in line with European ones, having about 60% of the residential buildings built before the 70s. According to this study, although the most representative type of size is that of single-family dwellings representing about 76.5% of the total, **the residential building with the highest number of dwellings is that of multi-story condominium buildings** (3 or more), which host about 18.9 million inhabitants compared to 11.7 million of the previous type. Another interesting fact is that [9] [10] the average annual production of residential buildings in Italy has gone from just under 200,000 buildings per year in the 60s and 70s to less than 29,000 between 2001 and 2018. The data gives an image of the extremely diverse building stock, in which many of the inhabitants are built even before 1918.

TAB. 2.2. EPOCHE DI COSTRUZIONE DEGLI EDIFICI RESIDENZIALI IN ITALIA

Epoca di costruzione	Stock	% sullo stock 2018	Incremento dello stock nel periodo	Anni di età degli edifici	Incremento medio annuo dello stock
Ante 1918	2.150.000	17,6	2.150.000	Più di 100 anni	
1919-1945	3.530.000	28,9	1.380.000	Tra 73 e 99 anni	92.000
1946-1960	5.190.000	42,5	1.660.000	Tra 72 e 58 anni	166.000
1961-1970	7.160.000	58,7	1.970.000	Tra 48 e 57 anni	197.000
1971-1980	9.140.000	74,9	1.980.000	Tra 47 e 38 anni	198.000
1981-1990	10.430.000	85,5	1.290.000	Tra 37 e 28 anni	129.000
1991-2000	11.230.000	92,0	800.000	Tra 27 e 18 anni	80.000
2001-2010	11.770.000	96,5	540.000	Tra 17 e 8 anni	67.500
2011-2018	12.200.000	100,0	191.000	Meno di 7 anni	28.667

Figure 2.3_ Eras of construction of residential buildings in Italy. Credits: CRESME

The distribution for the province of these data reports how the most recent buildings are present in the centres that had to cope with a post-earthquake reconstruction, on the Apennines and in the north.

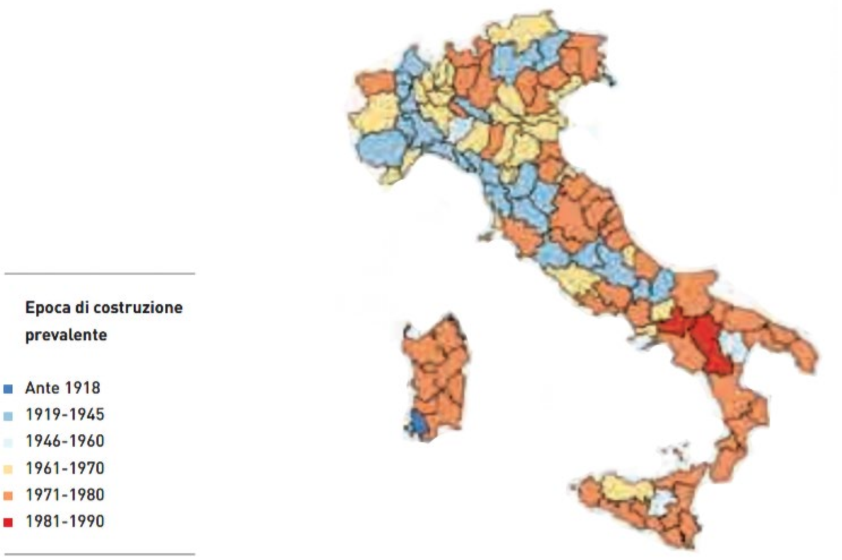


Figure 2.4_ Ricerca sul Sistema Energetico - RSE SpA

The situation is, therefore, that of the dated building stock, with a **strong percentage** of building achieved in the years **1946-1970**, "years of production marked by speculative models characterized by **low building quality**, among other things in the absence of anti-seismic regulations; a building stock that in 90% still has a measurable energy class between F and G" [2].

If the age of the building itself is not a problem or a source of amazement, it is important to point out that almost 5 million buildings (41% of the total, including abusive production) are built through forms of self-promotion or professional figures (site manager, master-builder, …) that little reflect the current design trend.

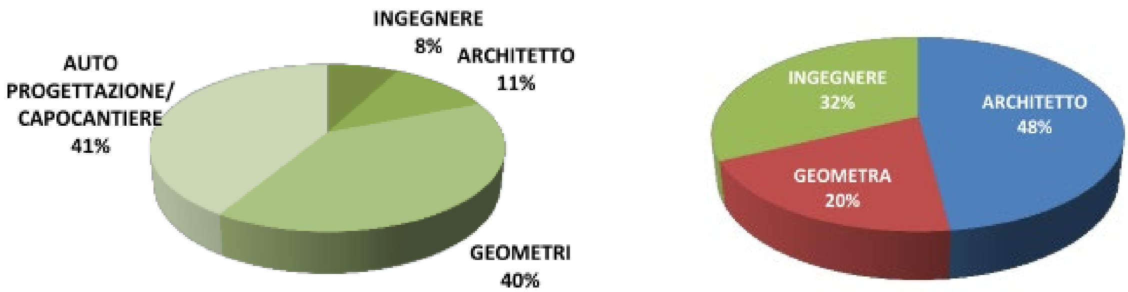


Figure 2.5_ Share of buildings per figure of the designer (left), professional figure in charge for new projects in the year 2017 (right). CRESME DATA SOURCE

With regard to the Italian situation, it is useful to remember that having such a high share of residential buildings built in the years before the 1970s means owning a building stock devoid of the most elementary rules of energy efficiency, which were introduced in Italy in June 1976 [11]. An example of this is the regional data collected where the average thermal transmittance of the building envelope is 1.09 W/m2K, more than four times the threshold set by the standard for the year 2021 [12,13].

The energy efficiency of Italian buildings

It can be said that a large part of energy consumption in Italy is linked to **civil uses**, most of which is due to air conditioning systems (**heating and cooling**), which absorbs about **70%** of final consumption.

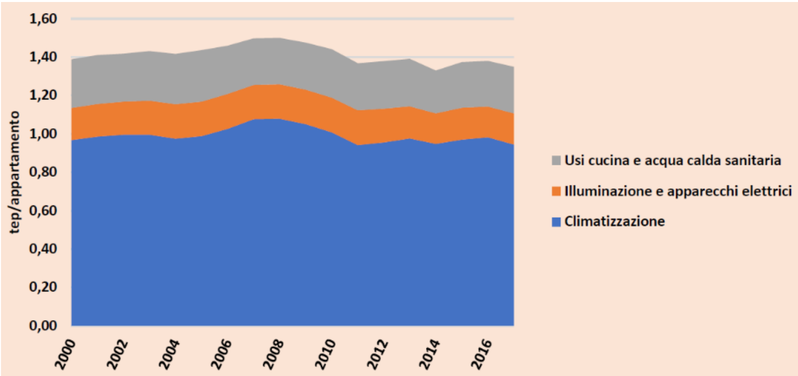


Figure 2.1_ Energy consumption in residential by type. Credits: Eurostat.

Given the difficulty in finding specific data on the energy efficiency of existing buildings at a national level, it was decided to refer to the study conducted by RSE in collaboration with the Politecnico di Torino focused on estimating the consumption for heating in existing buildings in the residential sector. In fact, according to ENEA data, these amount to 68% of the total.

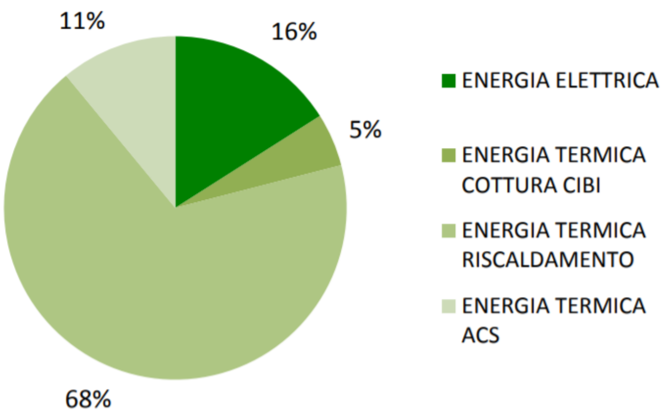


Figure 2.2_ Energy consumption in residential by type. Credits: ENEA

The energy performance of a building is strongly influenced by the era of construction, as it reflects the effects of the laws that have followed over the years and which have imposed increasingly stringent constraints on thermal dispersion and plant yields. In addition, even in periods before the first laws on energy efficiency in construction, the era of construction continues to be an important parameter in that it is linked to the construction techniques and materials used; finally, the size of the buildings (net height, average area of an apartment) and the type of thermal system (centralized or autonomous) are also related to the time of construction of the building.

By crossing the data on the number and surface area of the buildings and the specific consumption of the reference buildings of the study, two graphs were constructed showing, respectively, the average specific consumption and the total consumption grouped by construction period.

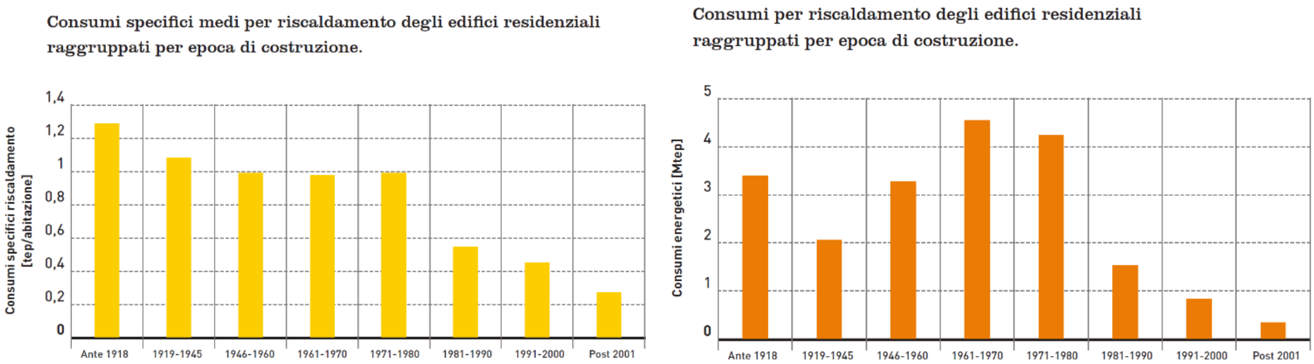


Figure 2.3_ Energy consumption in residential by type. Credits: ENEA

As might have been expected, the oldest buildings are the least efficient, but as far as total consumption is concerned, it appears that **almost 60% of the sector's consumption is attributable to dwellings built between 1946 and 1980** (of which 43% for the period 1961-1980 alone) and that only 14% comes from dwellings built after 1981 alone. This is partly due to the high specific consumption of these buildings and partly to their number.

It should be stressed that this figure is an indication of the high energy saving potential of the national building stock, also since buildings built in recent years are less likely to be located in historic centres and present architectural constraints that could limit interventions (facades) or increase their cost.

Taking up the *map Research on the Energy* System – *RSE SpA,* in the light of these data, it can be said that the older buildings are located more in the regions of the North-West of Italy where, due to a harsher climate, there is greater consumption.

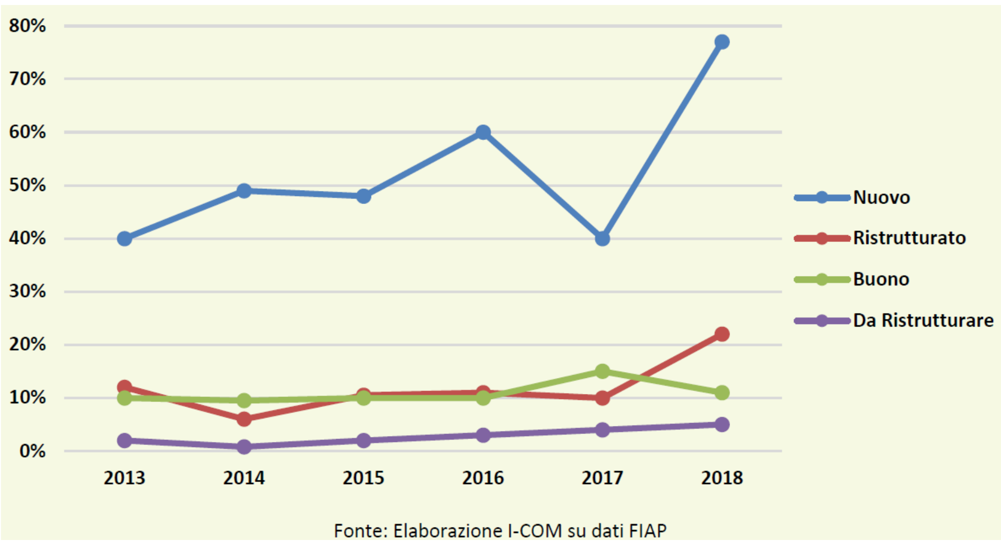


Figure 2.4_ Real estate sales in classes A+, A and B by conservation status, period 2013-2018 (WEEE 2019)

At this point, it becomes necessary to analyze the response of the real estate market to the presence of energy-efficient buildings. Taking up the trend of investments in housing, focusing on the last 20 years and comparing it with the trend of investments in energy-efficient properties, in the last year the volume of **purchase and sale of renovated houses with high energy efficiency has increased**: from 10% in 2017 to 22% in 2018 in the percentages of buildings belonging to the performing energy classes (A+, A and B).

As regards buildings subject to real estate transactions in 2018, 77% of newly built properties sold have a high energy quality (A+, A and B). The positive figure for new buildings reflects the need to comply with high regulatory standards, and the fact that the stock of unsold buildings - including buildings built some time ago - is being exhausted. It can also be seen that most of the buildings to be renovated belong to relatively low energy classes, which is why the efficient renovation market represents a developing sector with a wide margin of potential.

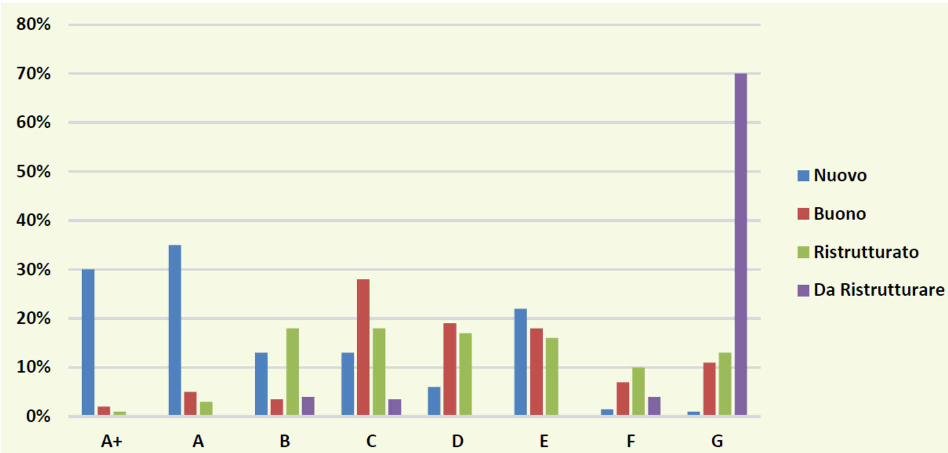


Figure 2.5_ % distribution by energy classes compared to the state of preservation of the most frequently purchased dwelling. Credits: WEEE 2019

The data show that most Italian buildings were built between 1971 and 1980, but there are no significant differences with the other periods examined: the data give us back the image of a fragmented Italy, of which a large part of the inhabitants turns out to be built even before 1918.

It is probably the union of all these factors that allow us to attest today annual energy consumption values between 160 and 200 kWh/m^{2}y, with average primary energy [3] demands for the winter period equal to 201 kWh/m2y and [14] emissions equal to 43.75 kgCO_2eq/m^{2}y [12].

It is evident right from the start the contrast between the consumption of those buildings designed at a historical moment when there was no attention on the issues of energy and environmental sustainability (about 250 kWh/m^2) against those of buildings built in the 90s (100 kWh/m^2) [15].

The reduction of environmental pollution has taken on a central role in the development of the construction sector and more and more attention is attracting [16] now and will attract soon.

Retrofit Market

With the need for a paradigm shift, the **energy renewal market is emerging in Europe and is playing a role as a strong stabilizer of the construction sector - and consequently of the European economy** - in the period following the 2008 financial crisis. To give an overall idea of the figures involved, it is estimated that it directly accounts for around 9% of gross domestic product (GDP) in the European Union and provides 18 million jobs, while, if we look at the entire supply chain involved, the European Union's internal market offers access to over 500 million people and around EUR 13 trillion of GDP [17]. In this context, therefore, the estimates of the European energy renewal market, which in 2015 were of the order of 109 billion euros with the creation of about 882,900 jobs, are not surprising [12].

After a brief recovery in the new construction market at the turn of the 2000s, starting from 2008 a steep new recession began for new constructions that lasted until 2016, but which will probably resume following the recent economic crisis due to the health crisis. On the other hand, apart from a slight decline in 2013, **the renewal market essentially contained the decline in the new construction sector**.

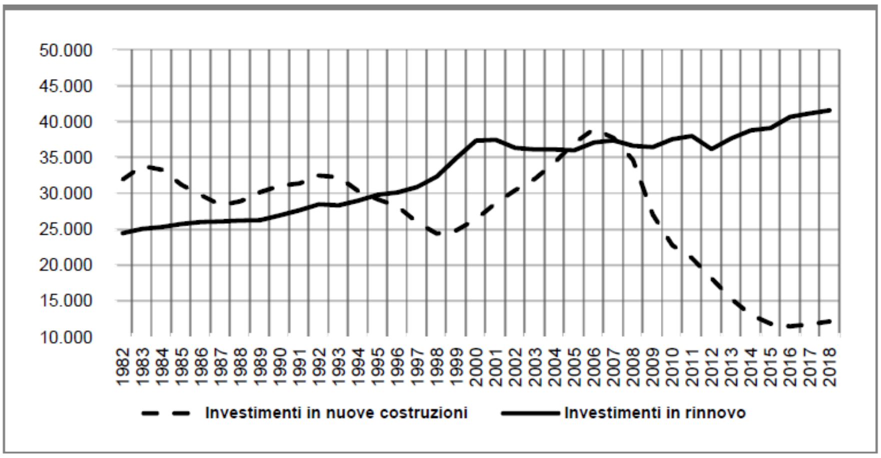


Figure 2.6_ Investments in residential construction 1982 – 2018. Credits: CRESME

As also documented by the ENEA reports and as will be reported later, the growth of the renewal activity is also due to the energy redevelopment activity thanks to the incentive measures.

Although some stakeholders say demolition and new construction are far better than renovating old housing complexes and while there are some reasons why a new home might be preferred to retrofit intervention, cutting emissions is not one of them. In fact, if both interventions aim to achieve a minimum primary energy consumption target, in the case of new construction the production of building materials requires a series of operations (extraction, processing, transport, ...) responsible for a large proportion of CO_2 emissions into the environment; on the contrary, a retrofit intervention will result in an emission-related to the production cycle of materials that is about half, as well as considerations [18] of energy expenditure and costs [19].

Many research works deal with this topic, presenting the impact of the different energy-saving measures implemented on the reduction of greenhouse gas emissions: while some introduce specific methodologies to evaluate the effects of different energy efficiency and environmental impact strategies [20] [21] [22] [23], others have provided overviews of research, development and application of optimal retrofit technologies in relation to the individual case study [24].

Incentives

Tax deductions are the amounts that the taxpayer has the right to deduct from gross tax, i.e., the total income tax that you owe to the State to establish the net tax due. The deduction directly reduces the gross tax, i.e., the tax calculated after any deductions, which act in terms of deduction of the taxable amount.

The deductions have been introduced and are used by the Italian State for two main reasons: **to give a boost to a sector now in crisis and to renew an inefficient and fragile building stock**, as we have seen in the previous paragraphs. Over the years, the impact of such tax incentives has grown more and more. In 1998, incentive investments accounted for 12.9% of the redevelopment of existing residential assets, while in 2019 they accounted for 55.3% [2].

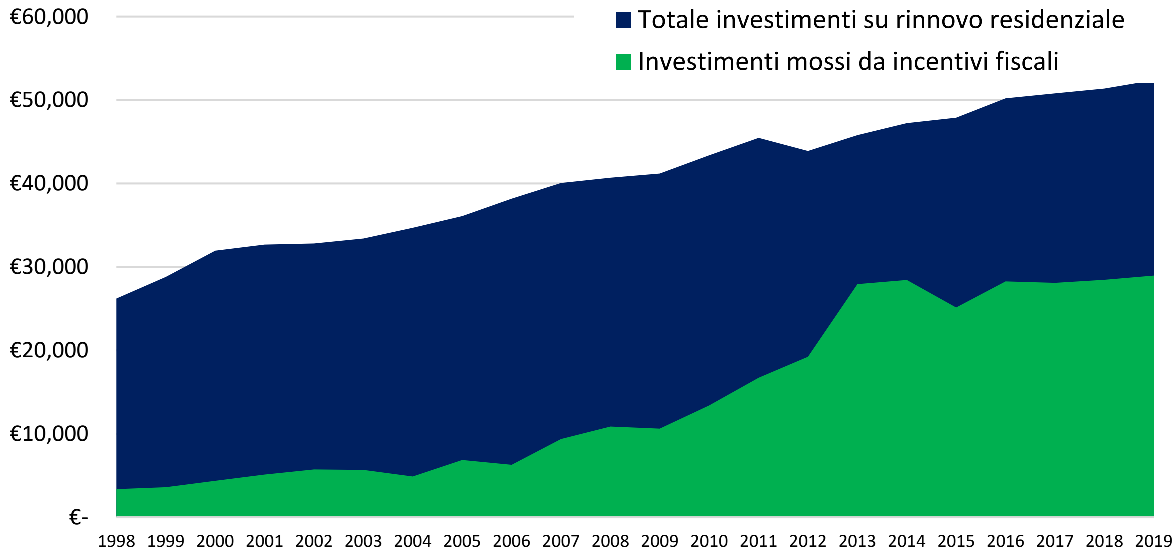


Table 2.7 _ Impact of incentives on investments for the renovation of residential buildings in millions of €. Credits: CRESME

The graph above shows that the renewal market has been increasingly fueled by incentives and has made an important contribution to supporting this sector. On the other hand, thanks to the further increase in the rates of the last *Decreto Rilancio* and the new *Bonus Facciate*, a new boost in investment in renewal could be underway.

The building deductions can be traced back to two macro-categories: building recovery and energy efficiency. The first includes: ordinary maintenance and renovation of buildings, reconstruction or restoration of damaged buildings as a result of calamitous interventions, construction of garages or parking spaces, elimination of architectural barriers, prevention of damage from illegal acts of third parties, energy-saving, adoption of anti-seismic measures **(Sisma Bonus),** works aimed at avoiding domestic accidents and maintenance of facades **(Bonus Facciate).** While the deductions related to energy efficiency, called **Ecobonus,** concern the following interventions: reduction of energy needs for heating, improvement of the enclosure, installation of photovoltaic panels, replacement of winter air conditioning or water heater systems, laying of solar shields, devices for the automated control of systems. As shown in the graph below, recovery interventions make up most of the interventions covered by the incentives and follow the investment trend shown in the previous graph.

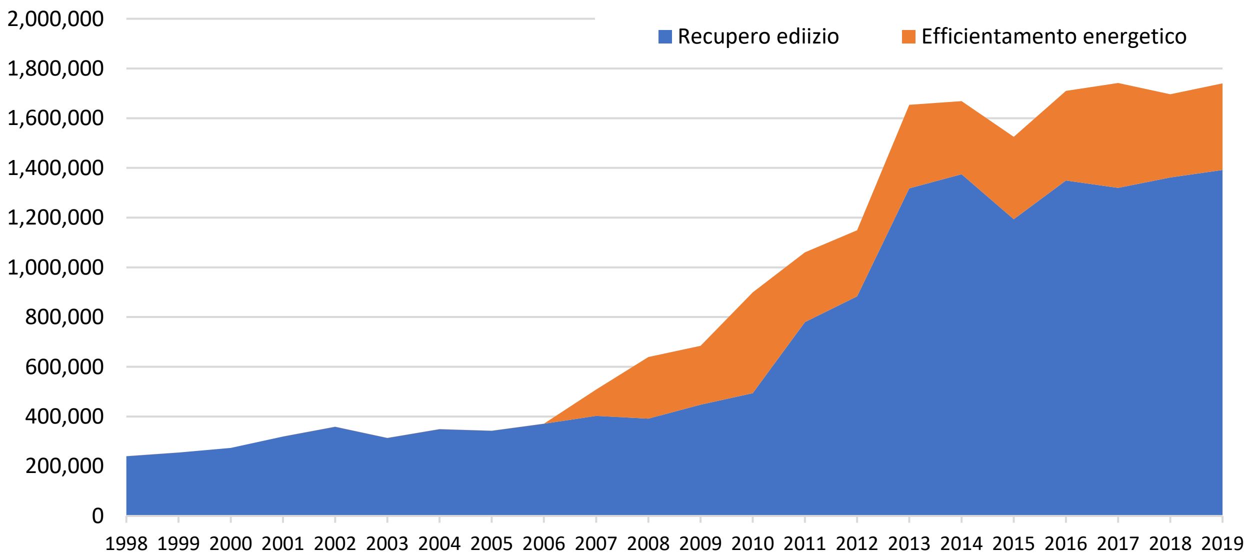


Table 2.8 _ Number of applications submitted to obtain deductions. Credits: CRESME

In 2006, the year of introduction of deductions for energy requalification, the contribution of **Ecobonus** in terms of the number of interventions was 106 thousand, which **in 2019** (according to CRESME estimates) tripled to 348,649 with a deductible amount of **about 1.78 billion €**.

Below is a summary table of the type of interventions most carried out under the Ecobonus. It is clear that envelope improvement measures account for the majority of applications received by ENEA, while overall retraining measures are poorly distributed in relation to the total.

TABELLA 3.4. - RICHIESTE DI DETRAZIONE PERVENUTE PER TIPOLOGIA DI INTERVENTO DI RIQUALIFICAZIONE ENERGETICA, ANNI 2009-2018

Tipologia intervento	2010	2011	2012	2013	2014	2015	2016	2017	2018
Condomini									477
Riqualificazione globale	1.917	1.450	3.579	3.566	3.753	3.308	3.517	4.276	2.674
Coibentazioni superfici opache e sostituzione infissi	226.720	170.400	135.283	244.421	213.581	204.233	207.570	234.593	164.057
Sostituzione scaldabagni elettrici	47.106	29.350	33.801	26.851	15.347	10.612	8.883	8.236	5.578
Impianti di riscaldamento efficienti	129.883	79.500	72.571	81.123	61.600	65.301	69.762	86.319	89.262
Schermature solari						47.674	69.874	84.953	70.491
Building Automation							661	3.614	2.307
TOTALE	**405.626**	**280.700**	**245.234**	**355.961**	**294.281**	**331.128**	**360.267**	**421.991**	**334.846**

Table 2.9 _ Number of applications submitted to obtain deductions. Credits: CRESME

Future objectives

The problem of **land consumption**, in particular cemented areas, in Italy is estimated at 57 million square meters in 2019 (about 2 square meters per second) [25] and pushes dense contexts to rethink existing space and infrastructure. The combination of the **rapid increase in the world population** that, according to estimates, will reach 9.7 billion in 2050 [26] and the percentage increase in the population that will live in **urban areas** (about 13% always with reference to 2050 compared to the current situation), may lead to a [27] significant - and worrying - increase in **GHG emissions** for all that series of inefficiencies that we have tried in part to bring back above.

The aim, in fact, is to promote a development that is less expensive in terms of natural space and based on environmental, economic and social criteria (need for integrated and holistic solutions), able to enhance the assets of the contemporary urban lifestyle [28].

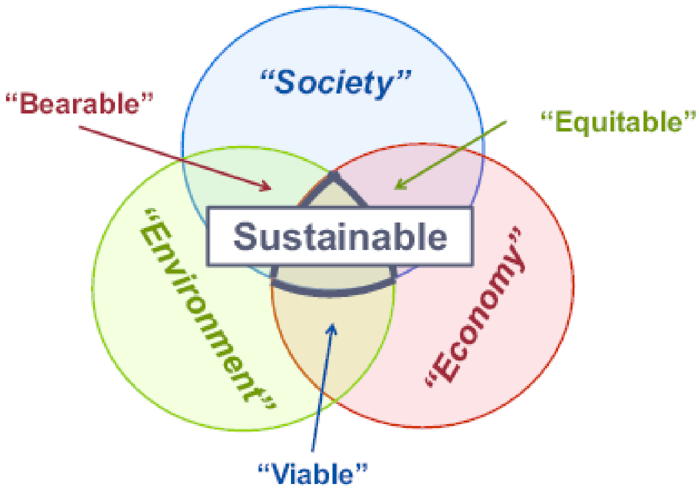


Figure 2.10_ The concept of "Triple bottom line"

At present, the European Union is facing a double challenge: **increasing the rates of renovation of buildings** while **carrying out deep renovations in the sector**.

Increasing the current EU renewal rate *from 1.2% per year to 2-3%* is essential to achieving both the EU 2030 targets - currently disregarded [29] - and in fostering the commitment made in Paris in December 2015. While a major energy restructuring of the existing building stock would lead to an 80% reduction in energy demand in 2050 compared to 2005 [12] levels, promoting more frequent use of renewable resources such as wood - and derivatives - or other biogenic construction products will certainly be a strong incentive to achieve these results. Energy will then [30] be saved, generated, stored and used where people spend most of their time: in buildings. This is therefore the level of performance required for most target homes if we want to achieve the CO2 targets set.

2.2 Prefabrication

CHAPTER'S SUMMARY:

The construction sector is still based on the logic of the mid-twentieth century, while since then all the largest industries have renewed themselves over and over again. The Off-site Manufacture, also called Design for Manufacturing and Assembly (DfMA) combined with a deep digitization process (BIM approach) form the basis of the Modern Method of Construction (MMC). The Platforms are part of this context, where several aspects of the project are managed holistically to increase the quality of the final product.

Each of the retrofitting phases has great importance and must be carefully evaluated in terms of technical parameters and indicators that will be useful for the planning of the intervention itself; some of the characteristic **steps for a deep redevelopment towards an almost zero energy-efficient market are** [18] [31] :

1. Assessment of the **market potential** and preliminary analysis of the building: first it is necessary to take into account all available options (value preservation, partial renovation, complete renovation, replacement of a new building, ...) leaving investors free to choose in which option to invest;
2. **Needs identification**: identification of the needs of the most important advanced retrofit stakeholders: owners, designers, builders and public authorities;
3. **Analysis** of the building: detailed analysis of the structure and its relevant system components in order to identify the best retrofit options among those available;
4. Agreement on **objectives**: the implementation of several retrofit options must not be ruled out a priori, in order to provide a high value-added construction strategy throughout the life cycle of the work;
5. **Planning** and design: of the entire project, including the design of any prefabricated elements (façade modules, ...)
6. **Execution**: During this phase, the actual realization on site of the project takes place, including all the parts that compose it;
7. Evaluation of the **effectiveness** of the objectives set: in the phase of use of the asset, it will be necessary to evaluate the actual achievement of the targets set in the design phase.

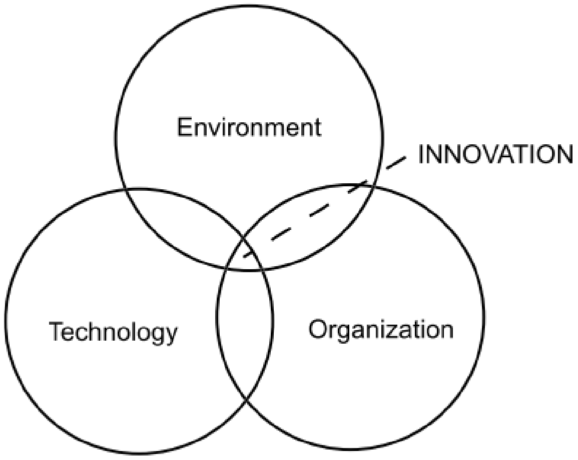


Figure 2.11_ Three criteria that have been proven necessary for innovation.

32

By focusing on the planning and design phase, to create zero-energy (ZEB) or quasi-energy (NZEB) homes, four **main areas** of analysis can be identified:

- **Boundary conditions**: climate is a key factor in the choice of specific technological solutions (D'Agostino and Parker 2018), both when the energy performance of buildings is analyzed, and when it comes to local renewable energy production, etc. The energy demand of buildings is in fact influenced by many climatic parameters, including outdoor air temperature, solar radiation (direct and diffuse), wind (speed and direction), air humidity, infrared radiation, etc.
- **Reduction of energy waste buildings**: before a retrofit action can be performed it is generally recommended to create a dynamic simulation model of the building using information from technical surveys and calibration based on the information in possession (energy consumption, etc.). Following the retrofit operation, it will be necessary to calibrate the "design model" using the data of the instrumental monitoring system thus obtaining a more likely version and perform test simulations, in this way it is easier to obtain the building's time constant, the actual thermal capacity and the overall thermal transmittance before and after a retrofit.
- **Adaptation to the use of buildings**: changing volumes, windows, as well as a general variation in exterior aesthetics has a major impact on the theme of architectural composition and therefore compliance checks may be necessary with the regulatory plans, building regulations, fire regulations, etc.
- Reconsidering the **behaviour of the inhabitants**: it has been pointed out that there is a considerable need for studies that need to focus on specific behavioural improvements; user involvement is in fact a major challenge in the restructuring process. This includes the reference to the so-called *Blue Table* which lists all the terms and conditions that are legally binding on the final contract with users (minimum amount of renewable energy for household needs, the maximum amount of users' energy demand, etc.) in order to avoid the so-called "*rebound effect*" [33], a "*phenomenon that improving energy efficiency may save less energy than expected due to a rebound of energy use*" [34].

Although these four macro-areas of intervention may each represent a very wide field of study, the current retraining processes usually focus mainly on the second item of the four mentioned above. In particular, we would like to point out that the common practice usually examines the concepts of reduction of heat loss through the envelope (areic, linear and point thermal flows) together with those of condensation formation that must be adequately studied and controlled (thermal bridges, etc.).

Each retrofit project should therefore respond, on a case-by-case basis, to the following ***construction principles*** and their effect on productivity:

- **Purpose**: extension or width of the project.
- **Quality**: design and construction excellence and their guarantee over time.
- **Timing**: program or duration of the project.
- **Costs**: capital and operating investment.
- **Risk**: exposure to any financial losses.
- **Work**: skilled and non-skilled human labour.
- Degree of **invasiveness**: disturbance to utilities and/or the surrounding environment.

Time	Can retrofit time be reduced from 10 days to 3? Or less?
Cost	Can the cost be reduced from €100 000 to €60 000 or even €45 000?
Performance	Can performance be guaranteed for 40 years?
Design	Can the installation of services be made more compact?
Disruption	Can the presence of workers inside the house be minimized? Can the turmoil to inhabitants be reduced?
Energy	Can energy generation match total energy demand? Can energy demand be managed?
Construction	Can the construction be done without the need for scaffolding?

Figure 2.12_ Key project-related challenges for the next generation of retrofits

In terms of technical problems, high costs and climatic constraints are usually the main obstacles to the implementation of modernization [35] measures. Long winters, such as prolonged adverse conditions, often hinder the smooth running of modernization work and in many cases, installations simply cannot be carried out. In addition, the presence of scaffolding for long periods on the external facades is also a strong disincentive (there is talk of about 12-24 months for seven-story buildings); in this meantime, the disturbance on the occupants who will have to seal the fixtures outwards, as well as the impact created on the surrounding traffic and the costs of occupying public land, are certainly a significant factor.

A whole series of problems could be listed, linked to the lack of awareness on the part of the **owner** of the building, to which are added the lack of funds and timeshare problems; for the **process manager**, on the other hand, long interruptions, as well as lengthy procedures, planning problems and administrative burdens. While the barriers for **construction companies** have been substantiated into four main categories (financial issues, market barriers, capacity building and industry structure), for **manufacturers** of materials and components the widespread adoption of innovative materials has been the main challenge to be addressed.

As already mentioned, the refurbishment of a façade affects the performance of the facades in terms not only of energy efficiency and life cycle cost but also of building performance, physical behaviour, durability and aesthetic appearance. Buildings to be restored have been built in different eras with different historical-cultural aspects, with different technologies and materials, and local climatic conditions give rise to different renovation needs. By combining these aspects with the economic conditions, ownership of the goods, building regulations and construction methods (that differ from country to country), you can see how the creation of a single system for the restructuring of buildings is severely slowed down [36].

Despite the presence of these obstacles at the design, operational and decision-making level, the architecture, engineering, construction and operations (**AECO**) sector is **increasingly pushing for a different approach** from the classic realization in operation in favour of increasingly predominant prefabrication of building systems.

In fact, **there is a strong need for an intense process of innovation** in the construction sector focused on **reducing costs, intervention times and guarantees of energy performance** [37]. In addition, technologies related to prefabrication turn out to be a resource towards the challenge of building renewal and urban renewal, but also a driving force in the development of new strategies and dynamic response to the future directions of the city and a new opportunity for urban and architectural research [15].

Today, while almost all types of industries are advanced with automated processes to accelerate, optimize and economize production, Jhon Fernandez [38] reminds us of how **the construction industry is the slowest of all industries** on the same scale to implement technological innovations. **The general meaning of "building" has not in fact changed drastically in the last eighty years,** while other sectors (automobiles, ship building and aerospace, ...) have reinvented themselves completely - even twice - in the last twenty years***.***

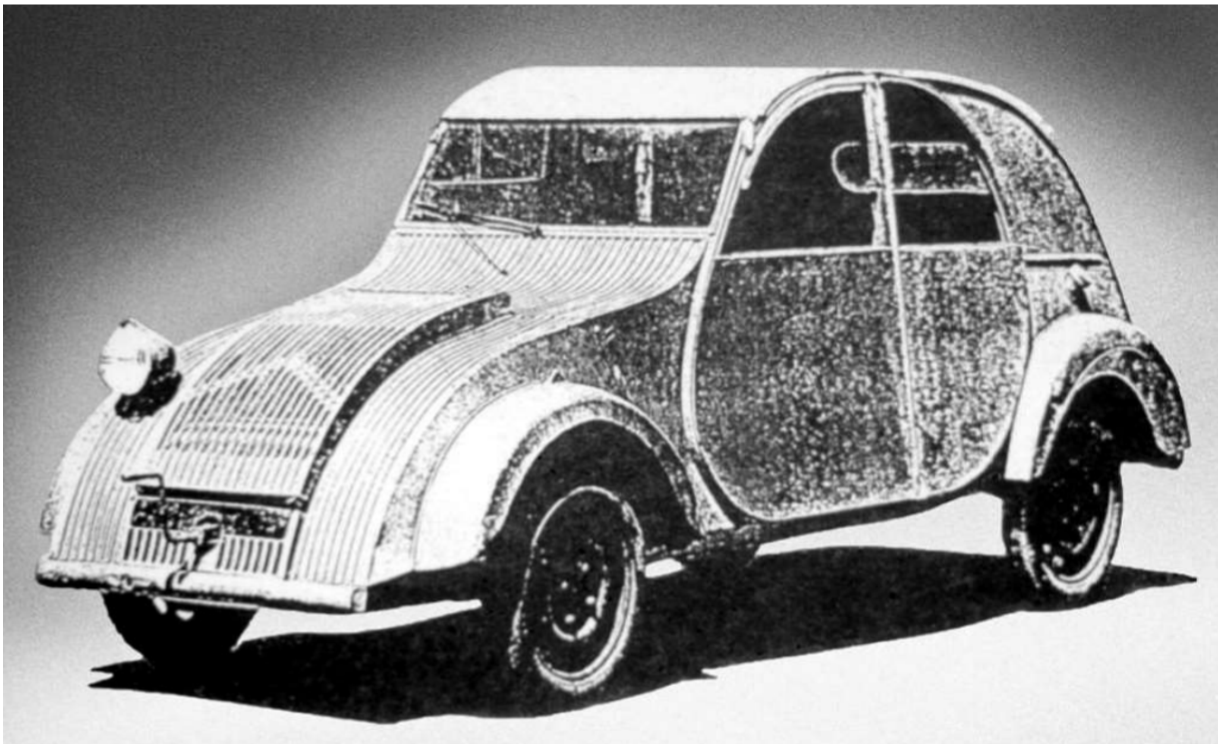


Figure 2.63_ Automotive industry – Citroën T.P.V. (1939)

Speaking therefore of the **prefabricated construction**, *this refers to the practice of producing building components in a manufacturing facility, transporting complete or semi-complete components to construction sites, and finally assembling those components to build buildings* [39]. We can immediately see how in fact the supply chain for the design, construction and manufacture of products is anything but united and continuous, but rather an extensive ad fragmented. If we asked ourselves what the term “pre” in prefabrication refers to, we would answer that [32] manufacturing was something that happened on site and therefore what we are referring to could be manufacturing and not prefabrication; the lexical problem reflects a lack of dialogue on methods and progress in the field of the construction industry in general.

Therefore, taking up what was said in the previous chapter, about the strong environmental impact of the construction sector on resource consumption, energy and greenhouse gas production, it should be stressed that part of the problem is related to the fact that the structures are still built on-site using methodologists and traditional craft work. This often results in the non-fulfilment of design requirements, compliance with budgets and established times, with constantly increasing costs and unacceptable consequences in terms of quality, safety and environmental impact.

Over the past 100 years, an **equation** has governed the economic aspects of the construction world [32] :

Q (quality) x T (time) = S (objective) x C (cost)

Regardless of which of the four variables we assume as fundamental, the other variables must remain in balance: to reduce the implementation time we must give up quality or spend more or lower the goal we have set ourselves, to increase the quality of the cons, we must increase the budget and/or time proportionally to the purpose.

In this general view, the designer will not only have to consider the design of the individual elements and the complete structure, but also the assembly process intended as opposed to the common concept of a building; in fact, the production process of the individual parts and the way in which they are connected as an integral part of the design process, rather than their adaptation after the event, is receiving increasing attention.

This is particularly important in the case of Modular Constructions, where the design of a single component depends significantly on the requirements of the assembly of the individual pieces in which the entire work can be broken down. Modularity is fully part of the **Modern Method of Construction (MMC)** and aims to improve quality and efficiency in the construction sector, where the problem of having high-quality standardized products meets flexibility in meeting the different needs of customers.

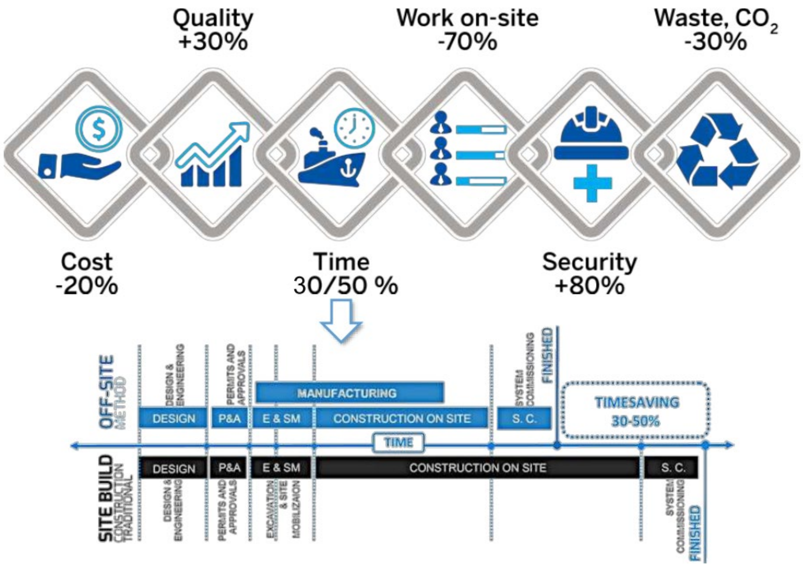


Figure 2.147_ Modern Methods of Construction (MMC). Credits: M. Cucuzza, Prefabrication 4.0

If, in fact, they focus on the distinctive characteristics of the product and their customization, the construction companies on the other hand rely on solutions that reduce costs and delivery times, increasing the overall quality. These objectives are sought by maximizing the amount of off-site prefabrication (including frames, coatings, coatings, services and surface finishes), minimizing the operations to be carried out on site. The modular constructions thus defined will have to look for the excellent degree of a mix between all these variables (which varies from project to project), embracing the **Design for Manufacturing and Assembly (DfMA)** to take significant steps in the field of construction.

The criteria that guide the choice towards this type of solution are certainly related to what was said in the points immediately above, but certainly stand out the ease of installation with the minimum possible level of intrusiveness (absence of scaffolding), which often results in a reduction in installation time of 20% or more; the management of the production process with quality standards, allows the reduction of production waste as well as the achievement of certain levels of performance over time, while the inherent flexibility of design of fastening systems, external surface finishes, etc. allows satisfying a wide range of requests.

Although in fact one of the greatest advantages of this system is related to the speed of implementation that allows to drastically reduce the construction time (especially where interruption means heavy economic losses in lost earnings), we must not neglect all those benefits related to the construction site environment rather than to the finished product. One of the most important is certainly linked to the fact that it remains a dangerous place, full of accidents and generally exclusive for men only, while there is a strong need for it to streamline logical proposals, to become a safer place and to allow the type of labour adopted to be expanded in order to remain safe, economically competitive and of major importance. In this sense, a strong boost could be guaranteed using a stable workforce with assembly methods regulated by an industrial logic, which is now widespread in many sectors except the construction sector, which, moreover, has much lower defect rates on end products than on-site construction.

The method can then be implemented until it becomes a real **Digital workflow** starting from the planning phase to off-site production and on-site assembly. Providing the essential data for the integration of the various phases on BIM data (Planning production design, performance control Offers economic optimization).

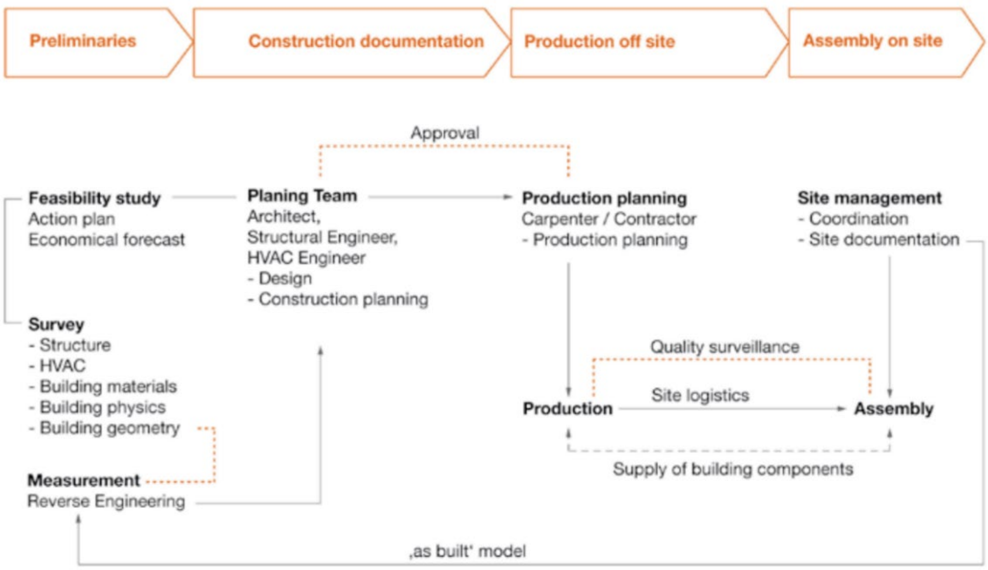


Figure 2.15 8_ Systemized Workflow

Design for Manufacturing and Assembly (DfMA)

DfMA is a design philosophy that emphasizes a holistic view of the design process, taking into account and analyzing in detail all the steps of a supply chain and construction process, but it should not be understood as a simple production of modules elsewhere from their final placement and their implementation, but must include other aspects such as Geometries (3D Models), Off-Site Manufacture, and Metadata (Building Information Model) [40].

The set of all these factors allows to enhance the final value of the product on the customer side, maintaining control over the delivery aspects of the designers, also making use of the knowledge, materials and technologies good practice of the built.

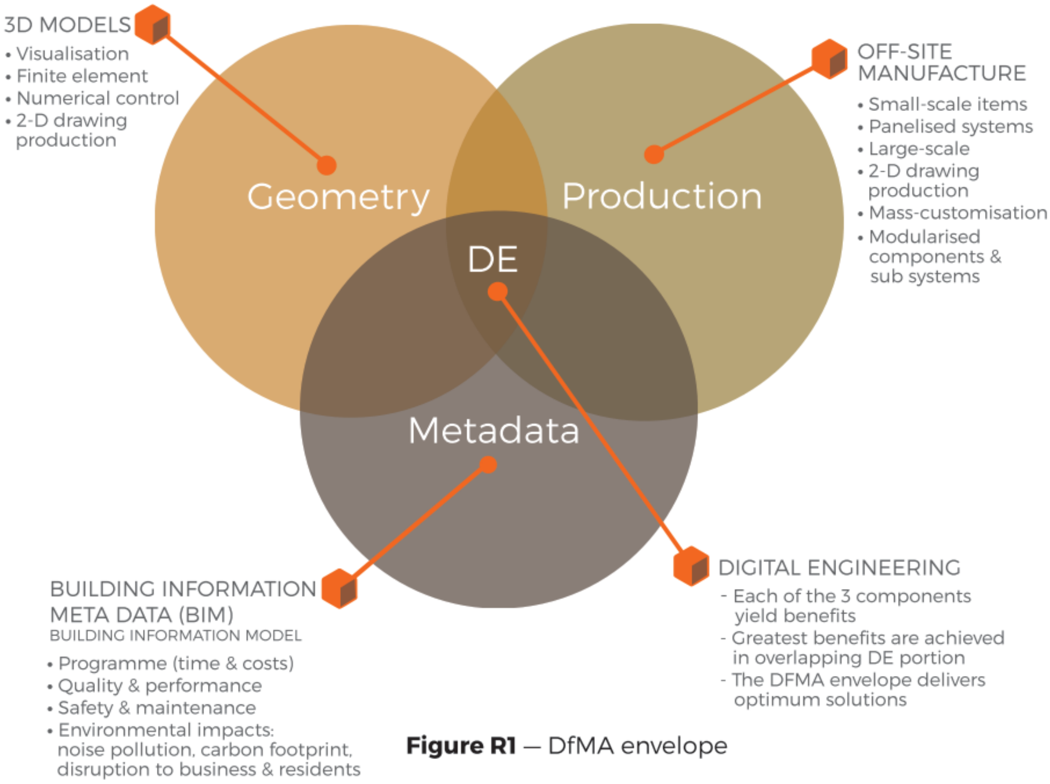


Figure 2.169_ DfMA process envelope. Credits: Monash University

How? The **3M method** helps us to better understand this concept, teaching us what to avoid during the production process: *Muda, Mura*, *Muri*.

- **Muda**: we mean futility, waste; it refers to both Transport (moving products that are not required), Handling (of vehicles and people more than required), Expectations (production interruptions during the change of design phase), Overproductions, etc.
- **Mura**: irregularity, lack of uniformity; refers to inconsistency in the workflow, caused by variations in demand irregularities, and is managed by introducing just-in-time control, production and delivery systems.
- **Muri**: unreasonableness, impossibility, overload, excess; it can be imagined as the situation in which workers are overburdened and can be avoided through standardized work.

Despite what has just been said, there are **several obstacles to the spread of the DfMA in the construction world**. These range from the negative perception of prefabricated structures by the public, the reluctance of most companies to adopt an off-site production system, the risk aversion of financial and investment institutions, the delay in new technologies to be accepted into the market, etc. DfMA's absorption into the construction sector has been slow, sporadic and limited to partial solutions (prestressed concrete elements, metal structural elements, ...) indeed.

However, **the conditions now seem right for a fundamental change in the sector** [41] :

- Issues relating to construction costs, availability and availability and labour productivity, market fragmentation, etc. are documented.
- United Nations data estimate that the world's urban population will increase by 2.5 billion by 2050. This creates the need to be able to design and provide resources highly efficiently to keep up with demand.
- BIM is becoming more and more "business as usual", so there are digital tools that would support a production-driven approach. This is a precursor to more sophisticated digital controls and workflows.

In order to reach the targets, however, **it is essential that DfMA is implemented from the earliest stages of the process**, paying particular attention to the following key concepts:

- Development of flexible and technical processes that encourage efficient off-site prefabrication of modular elements, easily transportable and quickly assembled on site.
- Organization of the construction site in such a way as to minimize adverse environmental conditions and social impacts, taking care that problems are reported, recorded and solved.
- Achievement of sustainable solutions at multiple levels (design, site, district) to be considered throughout the life cycle, including production and assembly.

In order to locate fields where standardization processes can be applied to add value without compromising functionality, solutions should be queried and filtered based on a process of: **Rationalization**, **Standardization**, **Optimization**.

We talk about **Rationalization** when controlling the proposed solutions, we choose to apply a series of tools to a group of elements with similar characteristics: it is in fact unlikely to think that we can apply the same concepts and procedures at the same time to a multi-story commercial and a residential building. It must be said, however, that the smaller the whole, the greater the possibility of focusing on him to deliver efficiency benefits; on the other hand, if a platform is too specific, it may not encounter sufficient market volume. The optimal situation would therefore be to be large enough to take a good portion of the market, limiting the complexity enough to be efficient.

When we talk about ***Standardization,*** we mean a process that can provide an adequate number of common solutions with a high number of occurrences; this will provide significant benefits in terms of design speed, ease of construction, opportunities for standardized machining, etc. This can lead to the formation of a supply chain capable of developing consistent and reliable layouts, to ensure compliance with current regulations, long life and the minimum number of defects possible.

Optimization is therefore mentioned when trying to achieve additional benefits continuously by refining certain components, which if they become highly repeatable elements, justify a heavy refinement effort; the process also lends itself well to a reduction in the cost of the product by optimizing the properties, thicknesses, etc. of the materials involved, to meet the requirements of robustness and durability without exceeding unnecessary - and harmful - oversizing. These actions see their benefits increase exponentially and influence when linked to a mass production process on an industrial scale.

Platforms

All these concepts are at the very base of **Platforms***,* meaning sets of components [41] that interact to allow the production of a range of products and services. The term was made by the software and manufacturing industries, where platform-based systems both supported rapid innovation and formed a basis for exponential growth and value. Industries that have taken a platform-based approach have experienced the following benefits:

- Savings associated with transactional and fixed costs.
- More efficient product development processes through the reuse of common elements and the adoption of "modular" projects (in this context "modular" refers to conceptual design elements rather than physical modules).
- The ability to quickly evolve secondary products or derivatives and flexibility in the design of product characteristics.
- The ability to expand the applicability of a product to meet changing customer needs and keep up with technological advances while maintaining economies of scale.
- The ability to adopt "mass customization", combining the flexibility and customization of bespoke products with the low unit costs associated with mass production (this is the upper right pane of the matrix on the following page).

Construction platforms would consist of components (products or sub-systems manufactured by several suppliers), **with known interfaces, which could be combined consistently and well defined to create high-performance assets. A platform is an integrated system,** and its purpose is to rationalize the assembly of components or parts to reduce the workload while providing sufficient customization flexibility to ensure the optimal long-term functionality of a building or asset. Platform design is a digital process in which a designer tries to provide an optimal functional and aesthetic solution while being aware and (where possible) adhering to the set of rules of an appropriate construction platform. The incentive to design with or within these constraints is to unlock the efficiency benefits of the platform or integrated system. This can be mapped to an efficiency vs. effectiveness chart, where:

- Effectiveness is the ability of a building or asset to deliver the required business or social outcomes.
- Efficiency is the total cost of the entire lifecycle required to achieve this result.

The construction of the platform is an integrated and digitally-enabled logistics process that brings together components and subsets.

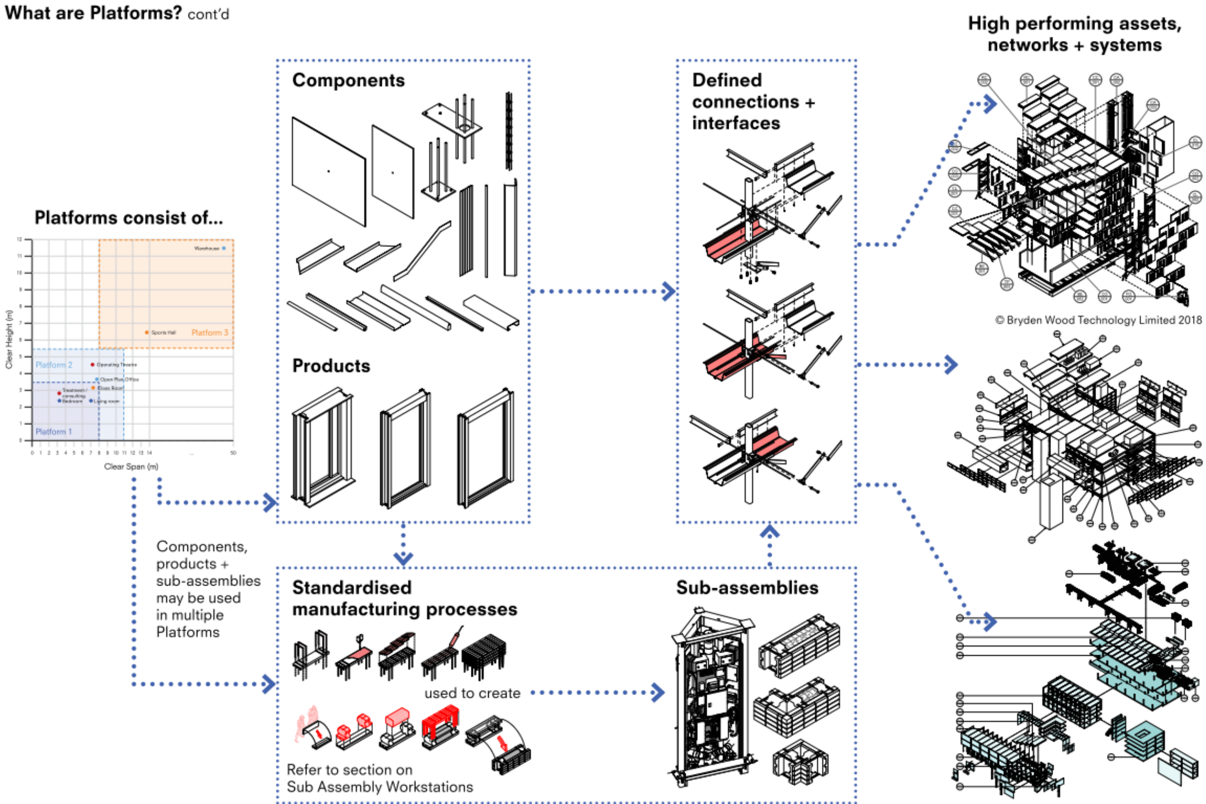


Figure 2.1710_ What are platforms? Credits: Bryden Wood

The construction already incorporates manufactured products and systems into its processes and raises the question of how platforms can offer significant advantages over these existing systems. Typically, though, existing products offer value to the manufacturer in the form of profits from sales without necessarily transferring that value to the supply chain or end customer: improvements in the product result in incremental increases in value for the manufacturer (in the form of higher profits and/or market shares). The existing construction brings together a range of these systems and products, where the benefits are "outward-facing", i.e., captured by the supply chain. In contrast, a platform-based approach is designed to maximize the efficiency and effectiveness of the entire system, creating cumulative gains. The platforms become then the link between a highly productive manufacturing sector and the construction industry.

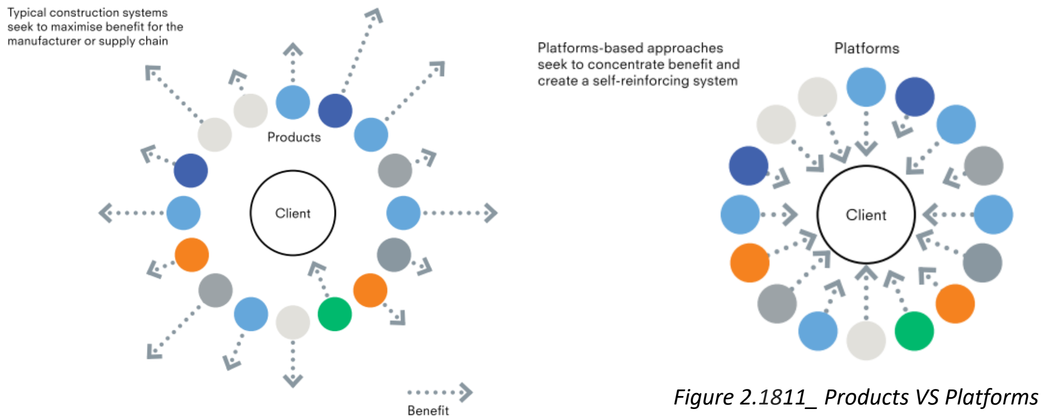


Figure 2.1811_ Products VS Platforms

Time and Cost

This, then, is how seizing the opportunities for renewal could be a real advantage for European economies and society. Some studies [42] have shown that the **efficiency process can offer a huge win-win opportunity**. This approach refers to all those seemingly not directly related factors, such as damage to human health, climate change and constraints on the foreign policy objectives of energy-importing countries, which could be mitigated with correct investments in energy efficiency.

Speaking of offsite constructions and in particular the advantages that it brings with it, the **speed of construction** certainly stands out. Very strong improvements in this direction are achieved, with construction times reduced by as much as 50%–60% in cases where large portions can be prefabricated, with values almost always exceeding about 20% [43]. The speed of construction also gives more financial benefits to building developers in the form of reduced financial costs.

In fact, there are already some realities in which an attempt has been made to find an appropriate form of payment which would entice [18] the user to invest in a retraining process and consist in the fact that the sum of the old monthly energy bill can be considered as a capital of investment; a loan of 25 or 40 years of the same amount, provides an investment budget for retrofit.

Considering that the retrofit payback periods are substantially longer than what is normally considered acceptable, a different approach has been studied and is based on the **Return On Investment** (**ROI**), generally expressed as [44] :

$$ROI\ [\%] = \frac{Operating\ Income\ [€]}{Total\ Cost\ [€]}\ \text{x}\ 100$$

The ROI indicates in percentage how many earnings are generated by an investment, in fact, while in the numerator we find the operating income (including taxes and extraordinary management) in the numerator we have the total costs of the expenditure carried out.

For those who manage a cash flow, the **Return On Equity** (**ROE**) variable is in fact the most interesting variable, because it measures the return on equity and indicates how much this returns to the generic investor a certain amount invested. When we talk about *Equity* we, therefore, speak generically of the access barrier for the investment, understood as an advance or fixed fee that must be paid to physically acquire the asset. The formula for the calculation is:

$$ROE\ [\%] = \frac{Net\ Profit\ [€]}{Equity\ [€]}\ \text{x}\ 100$$

The revenues obtained, therefore, appear in the numerator, while all the costs incurred appear in the denominator, such as example the advances and the portion of the loan paid at the time of sale, and the sale price of the property. The higher the ROE, the more attractive the intervention, thus resulting in an important index for current and potential shareholders.

Then, ROI expresses the profit compared to the total cost of the investment, while the ROE expresses the profit compared to the personal cost of the investment.

As shown, for energy efficiency savings to cover the costs for this requalification, the overall **prices for intervention must fall drastically** and therefore delivery times must also fall by months rather than days, thus making even the intervention more attractive to the end-user.

Finally, the fact that the flow of money to the different companies involved is managed in a better way, for example for large-scale volume systems, the terms of standardization of business from suppliers are more similar to models in the industrial sector where payments for goods supplied fall after delivery and acceptance by the customer. This is possible, however, only by adopting a broad-based program rather than a series of individual projects.

Although in this first phase of experimentation there are still some doubts about the real creation of a reference market, once the prospect of substantial demand and an adequate supply becomes evident, lenders will be able to evaluate this new proposal to invest in tailor-made financial products [37].

For an analysis that wants to be as detailed as possible, however cheap a prefabricated solution may be due to time and labour savings, there are "**hidden costs**" that must be properly studied and managed [32] :

- Overheads: production facilities employ full-time staff and have facility costs such as equipment (purchase, maintenance, ...), space lease and monthly utilities;
- Transport: transport due to prefabrication is greater per unit volume due to the fragmentation of panels, modules and components that are often shipped with less compensation than on-site and well-packed materials and products;
- Setting: Although weight is usually not such an important issue, lifting a prefabricated element can be inconvenient and require skilled workers or dedicated teams to set up items;
- Design costs: Because prefabrication requires greater coordination with construction and manufacturing teams, architects and engineers can charge higher fees for the time investment.

The fact that there are challenges that still need to be fully understood should not be frightening, especially if the alternative seems to invest only 50% of the total cost in residual value [41]. The rest is in fact spent on risk management related to the design and construction phases, compensation/profit/general expenses for the various parties involved, etc.

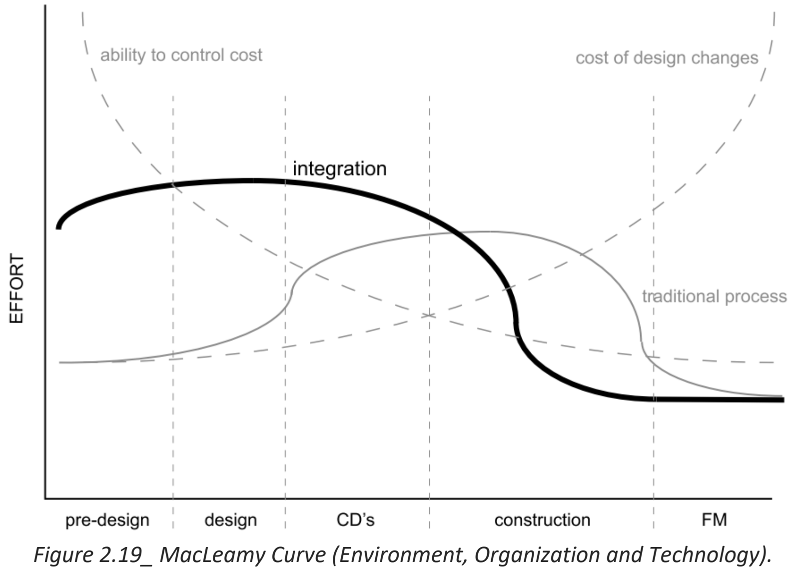


Figure 2.19_ MacLeamy Curve (Environment, Organization and Technology).
Credits: Smith, R. E. Prefab Architecture: A Guide to Modular Design and Construction

To better understand what has just been said, let us analyze the graph above, called the "**Mac Leamy curve**". It illustrates the concepts of the different decision-making phases, showing how choices made in the very early design phases positively influence the result with minimal cost changes. For this reason, **changes in the field of prefabrication must be made as soon as possible to control costs and generate benefits**.

Prefabrication-Environment

As a natural consequence of this push towards prefabrication, questions have been raised about the environmental impact of the construction world. Numerous studies have been carried out in this regard, with a particular focus on **Energy Consumption** [45] [46] [47] and **CO_2** [48] [49] [50] emissions, while the theme of **Life Cycle Assessment (LCA)** has found more and more space within this discussion [51] [52] [47] [53]. The results of these are studies have led to important considerations.

First of all, if the service life can be extended through modernization interventions, especially when the structures have strong residual value, this can be one of the most effective approaches to mitigate the environmental impact of buildings. The re-use of the materials, generally reflected in the grid structure or external façade is a key step to extend the life of the building and save the amount of energy built-in in the materials of existing buildings. Another important consideration is certainly the joint study of LCA e LCC (Life-cycle Cost) to analyze the environmental and economic sustainability of modern construction systems to support the decision-making phase and provide strategic support. The last observation is that as the building gets close to the net consumption zero of the energy in operation, the environmental impact of the production phase of the chosen system becomes predominant.

For this reason, the discoveries made that the prefabrication method allows you to reduce upstream emissions and the consumption of energy becomes even more important. For a more detailed analysis in these terms, however, it is necessary to carry out different combinations of materials that will give instructions on the choice of the most environmentally sustainable solution, also and above all considering all those phases after the implementation of the system (cleaning, maintenance, repair, replacement, and disposal). Just to mention a few indicators reference, we can refer to [54] to Greenhouse gas protocol (GGP) - Carbon Footprint, understood as global warming potential in 100 years for the assessment of emissions and CO2eq savings in the atmosphere [kg CO2eq] and at the Cumulative Energy Demand (CED), i.e., to the cumulative energy demand to calculate the consumption of renewable and non-renewable energy of the process also considering the energy of the raw materials [MJeq].

DO	DO NOT
Use recycled materials	Use all new material
Use recyclable materials	Use single-life materials
Use a few materials and components	Use many different types of materials and components
Use natural and non-toxic materials	Use toxic and hazardous materials
Use easily separable materials	Use composites that are inseparable
Use mechanical or natural finishes	Use composites that are inseparable
Use mechanical or natural finishes	Use applied coatings and finishes
Provide permanent identification of material type	Use materials that end of life reuse is unknown
Use mechanical connections	Use chemical connections and adhesives
Use a changeable adaptable system	Use fixed unchangeable systems
Use modules, panels, or components	Use non-standard sizes or configuration systems
Use standard construction methods	Use highly proprietary systems
Separate building systems	Compress systems requiring one and all to be changed
Make materials able toe be handled	Make systems that require difficult labor sequencing
Provide a means for handling	Neglect construction sequence process during design
Provide realistic tolerances	Make building too tight
Use fewer connections	Use infinite fasteners and connectors
Design durable joints and connectors	Design one time assembly connections
Provide parallel sequencing disassembly	Detail construction process to accommodate linear path
Use a structural/assembly grid	Make every component and joint entirely unique
Use lightweight materials and components	Use heavy and cumbersome materials and components
Permanently identify points of disassembly	Make assembly and disassembly obscure
Provide spare parts and onsite storage	Make a proprietary system where there is just enough

Figure 2.20_ Strategies to reduce embodied energy.
Credits: Smith, R. E. Prefab Architecture: A Guide to Modular Design and Construction

Speaking of the relationship between prefabrication and the **use of materials**, it is worth remembering that for constructions on site it is estimated a **waste of new materials** brought to the construction site equal to 40%, while the [32] modular system cuts waste on materials for an estimated peak value of up to 50% making the construction production [55] [56] processes more sustainable and efficient in the long term. Another important theme related to this is the process of dismissing the building, which instead of being **demolished** can be **disassembled** for new reuse of materials. Traditional on-site demolitions typically use large machines that basically make large portions of the building rubble; this demolition method results in mixed, damaged, and even contaminated waste that immediately devalues the material to the waste threshold. In addition to this, it must also be considered that many collection centres for waste streams, do not reorganize the incoming material, with the consequence that many elements still valuable (metals, etc.) are lost in landfills, the last step of the hierarchy. The ability of the modular structures to disassemble the different components no longer makes demolition necessary by favouring potential reuse; the advantages are also to be found at the level of management of the entire process which therefore becomes more orderly, with less pollution from dust and noise. It is important, however, that this process is designed upstream, with a well-organized study and coordination, because if traditional demolition systems were applied to a prefabricated system it could even increase the degree of contamination of the waste stream. In essence, therefore, if properly organized, the volume of waste can reach high values (some studies suggest even 85%), becoming in fact the second source of revenue for producers, transforming decommissioning costs from losses to profit.

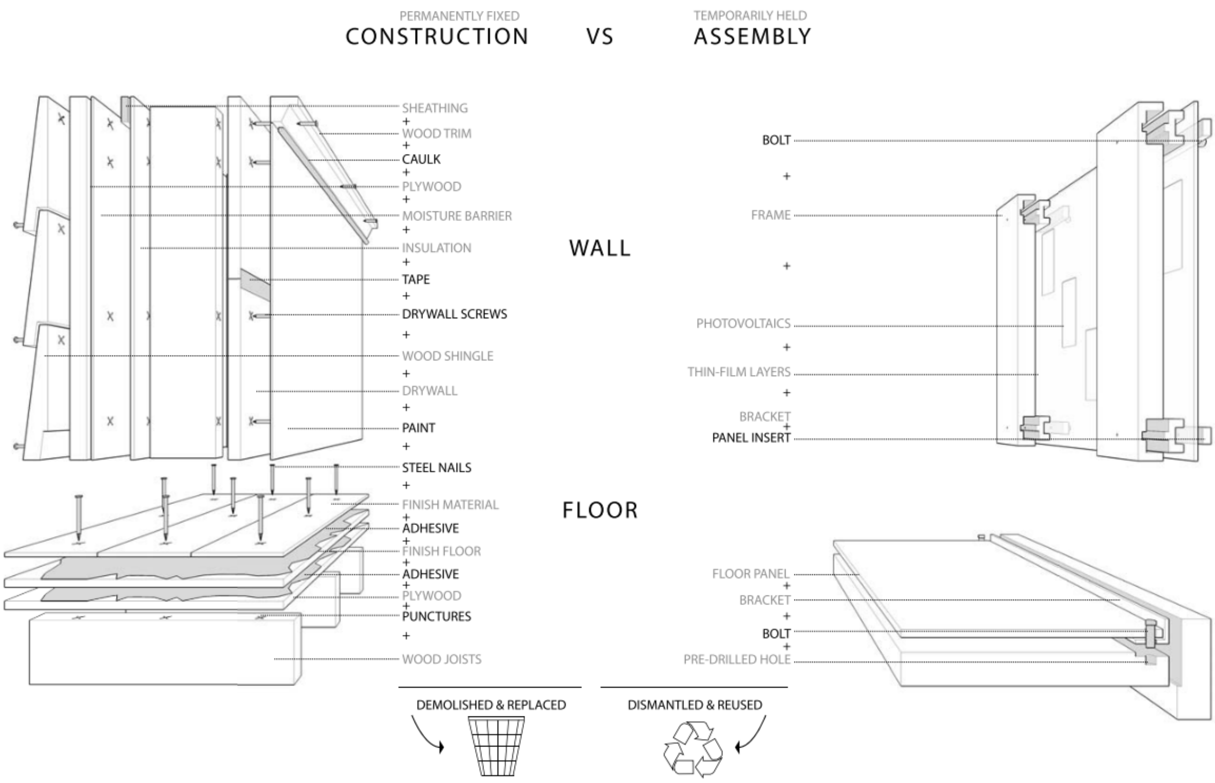


Figure 2.21_ Assembly diagram.
Credits: Smith, R. E. Prefab Architecture: A Guide to Modular Design and Construction

Finally, let us talk about the relationship between **prefabrication** and **greenhouse gas emissions**. Although studies have shown [57] that there is a linear correlation between CO_2 emissions due to component production and the Prefabrication Ratio (PR), in reality, this correlation is very unlikely to exist due to the fact that many factors influence the number of emissions when the different components are prefabricated. If we read the results obtained from other studies carried out on the same topic [58] [59], we are more legitimate to think that emissions do not necessarily decrease with an increase in the degree of prefabrication: the minimum level of pollutants is reached for certain intermediate levels. While they differ substantially on the value of CO_2 emissions achieved by a PR = 1 compared to conventional systems, they basically agree that an on-site assembled system has cost-effective values that are substantially comparable (if not even better) than a fully prefabricated system. However, it is important to emphasize that as the degree of prefabrication achieved increases, carbon dioxide emissions move towards the production and transport phase and that therefore new focus on these and other areas (operational, disassembly and recycling) are necessary, especially in the search for a precise relationship that links carbon emissions with a degree of prefabrication. The few studies found [43] so far, however, highlight how the accommodation services and services of the staff, as well as lighting systems and equipment, are strongly dependent on the number of hours of work of the workers on-site and that therefore significant benefits can be achieved even in these terms. Furthermore, given the fact that often men and materials arrive/leave the site by means of a series of means in a fairly random way, it would be possible to obtain both advantages on exhausted emissions if these means were carefully programmed and of adequate size so as to reduce the number of them as much as possible.

The bridge with BIM

One of the most important approaches to modular constructions is to adopt **rich digital communication** and in this, the **Building Information Modelling (BIM)** software can help significantly in interoperability, quality of information and collaboration between the project participants. BIM should be considered as a complex process not only made of managing project documents in three-dimensional dimensions but also as a tool for managing the subsequent design phases. **The BIM implementation is not really about software as much about the change of organization that it brings**: experience has in fact taught how people and processes are far more important than technologies [18]. Its importance, however, is such that it is thought that the greatest growth in productivity in the construction sector will come from off-site automated activities highly facilitated by the BIM approach [60], although it is still believed that the BIM knowledge curve is one of the biggest barriers to its diffusion in the construction sector [18]. In order to reduce the number of changes on-site, in fact, it has the benefits of improved design software, with reduced errors/design changes, precise and multiple amounts of information, as well as real-time collaboration [61].

To be truly effective, all data (finished models, geometric components and computer numerically control models (CNC), etc.) **must be effectively structured**, properly managed and updated through all design and construction phases. A portion of the work could in fact be automated and carried out by robots in the short future and they need input provided through **Computerized Numerical Control (CNC)** software derived from the different models present.

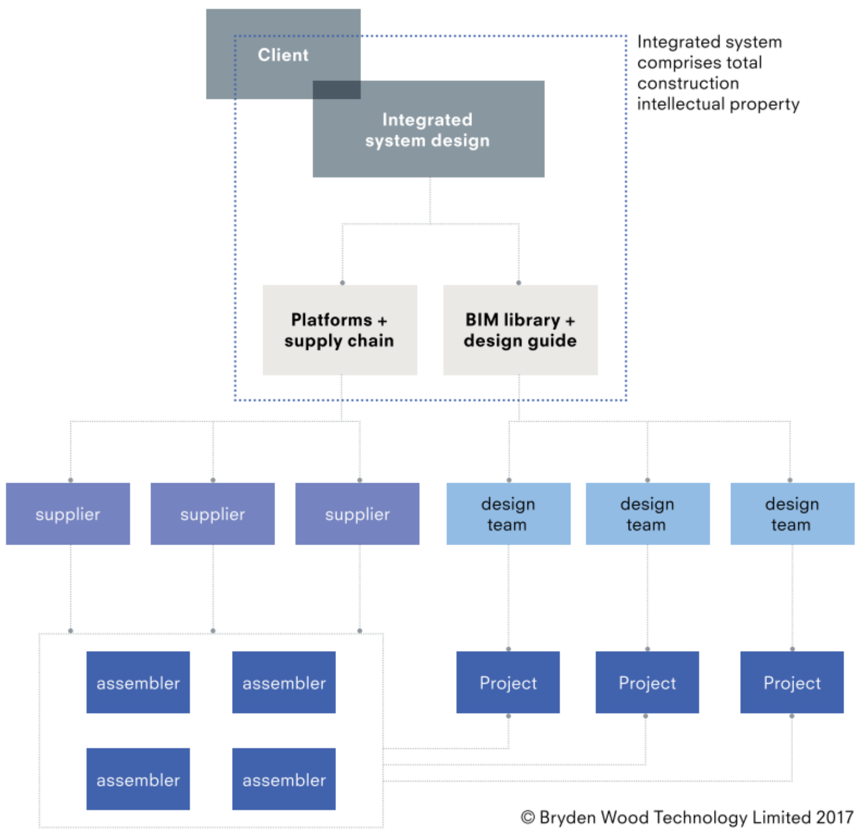


Figure 2.22_ Potential procurement route for an integrated programme-wide solution. Credits: Bryden Wood

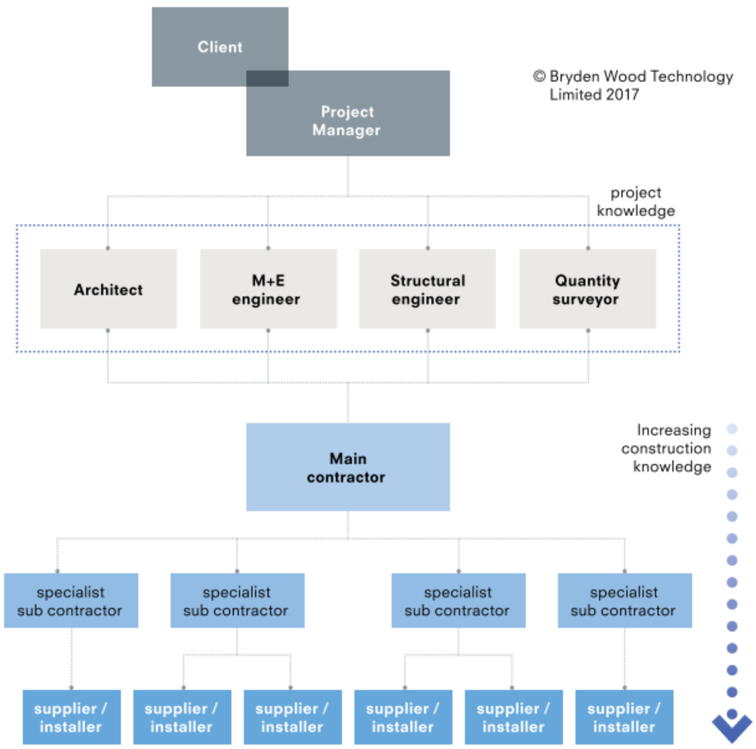


Figure 2.23_ Traditional procurement route. Credits: Bryden Wood

The basics of design for Manufacturing and Assembly is therefore a virtual reality modelling of the project, which includes:

- Discretization of construction.
- 3D design collaboration.
- 4D construction planning (Time).
- 5D quantification and costing (Cost).

Another important theme is that of compatibility between the various parts, simulated construction processes and elimination of **clash**; since modular constructions are assembled only in the final phase, that is, when most of the other components have already been made, this part is particularly important, even more so than in traditional constructions. It is therefore important to close the gap that traditional constructions generally have between the different parties involved and to develop a holistic process that considers every single decision, so as to severely limit the interface problems on site.

The last related topic is the formation of a **Metadata Model as a multi-dimensional database containing all the relevant parameters of the project**, to support all the figures involved in improving the management of the process. **The fields of application can be the most diverse, starting from the management of timing, assembly sequences, costs, etc. but also environmental impacts such as carbon dioxide footprint, sustainability, etc. When combined with a 3D geometric model, it is, therefore, possible to evaluate all design options.**

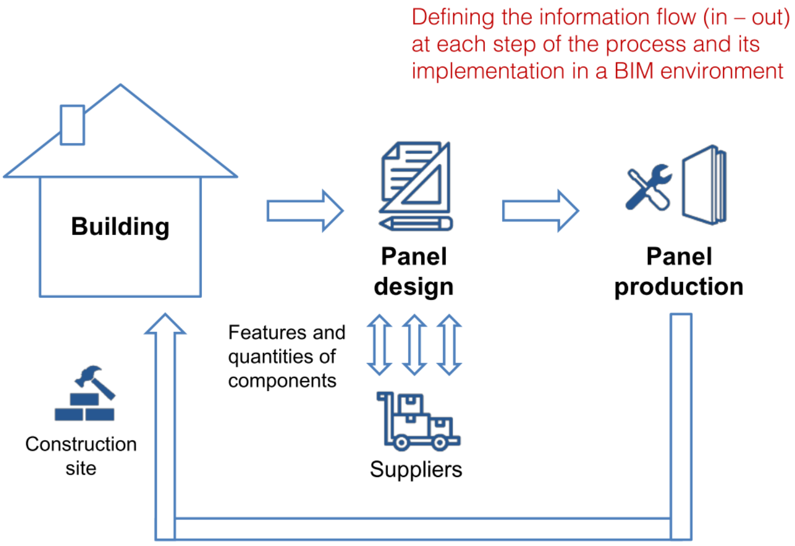


Figure 2.24 _ BIM-enabled design

In any case, an adequate amount of information regarding the building, its services and its operation are essential to obtain a solid and useful model. However, as some studies have pointed out [63], there is a serious problem of a lack of information in energy assessment models, to be understood as the absence of a systematic collection of data on the stock of existing buildings, especially in the case of post-event additions. Since a deep knowledge of construction in existing buildings is the key to the development of modular deep-retrofitting solutions and since redevelopment operations appear to be cyclical phenomena [18], this can be a major obstacle to its development.

In addition to this problem, the **more frequent weaknesses** which are being advanced are the necessary high level of integration in terms of Information Technology (IT) to rationalize the Off-Site Manufacturing (OSM) process, the difficulty of modifying the modules constituting the building due to changes in construction or customer demand conditions and problems related to the transport of large components. While we can fully rely on BIM technologies (which cover a large amount of information about the attributes of buildings and construction processes) to answer the first problem, it is also true that it contains attributes that can facilitate the reassembly of small parts into larger components to respond to problems related to transport size. Finally, with regard to the difficulties of making changes after the event, the ability of the new instruments to rely on parametric rules, any modification made on a component, also brings updates to other objects that are connected to it; moreover, the possibility provided by the models to detect inconsistencies, clashes and omissions, allows users to solve problems before conflicts arise.

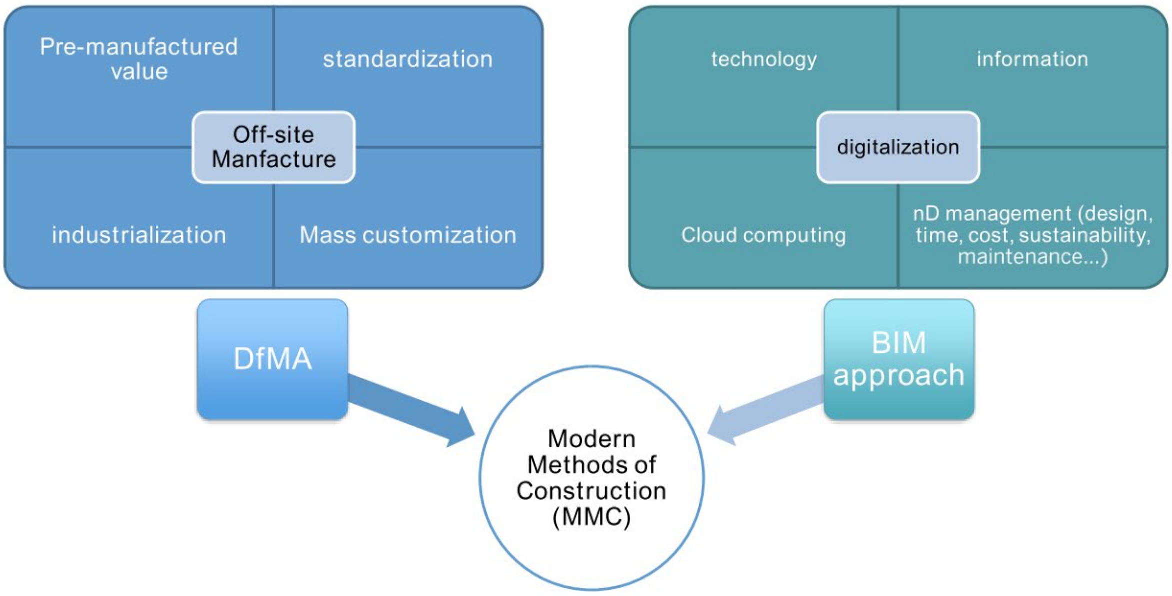


Figure 2.25_DfMA & BIM Approach

Final considerations

It is then felt the need for the formation of **ONE-STOP SHOP** [18], i.e., companies/consortia that offer a variety of products or services to their customers so that all its requirements can be met in that position. Compared to several individual institutions to meet each need separately, the one-stop shop saves the consumer a lot of time and effort. The concept is not new and certainly not exclusive to (n)ZEB projects, yet there is a difference. Within the (n)ZEB renovation projects, there are some issues that should be included in the project, such as performance assurance, maintenance and/or long-term renovation contracts, etc. This shows the **need for the interrelationship between the various issues**, but it is difficult for construction companies to offer products or concepts in line with what has just been saying.

As we have seen on several occasions, **dynamic and multi-objective solutions are required** throughout the time of this process, from the relief of the existing building model to the development of the project. A natural consequence of this fact is therefore that the software [21] used must be capable to develop parametric simulations and multi-criteria minimization since it is desirable that individual parameters commonly used to describe some of the properties of the various parts of buildings (such as thermal transmittance (U) and solar factor (g), etc.) are replaced by global analysis criteria. Although one could argue about the comparison between these analyses and those ones carried out on real buildings, the latter is difficult to achieve; the need to design of the individual components, prediction of the different construction phases as well as calibration of the different parameters to test how good the work has been carried out, ... make everything specifically not feasible and it is necessary to intervene with the models described above, which must therefore be as calibrated as possible.

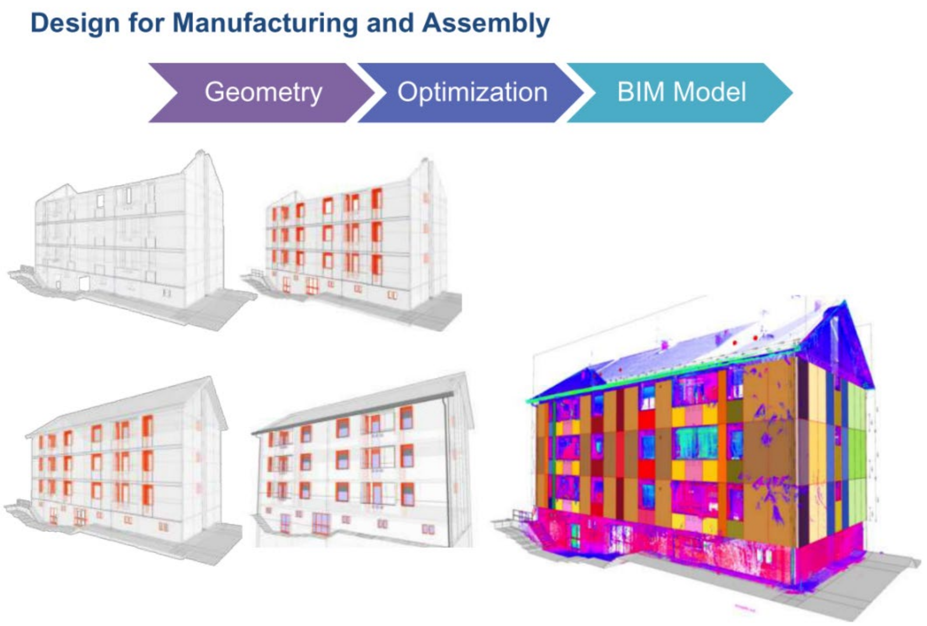


Figure 2.2612_ Design for Manufacturing and Assembly
Credits: Integrated approaches for large scale energy retrofitting of existing residential building through innovative external insulation prefabricated panels

3. GOALS

3.1 The Purpose (Why)

Some themes dealt with in the previous chapters such as the renewal of the residential building sector and the importance of interoperability between individuals participating in the realization of a project, have stimulated our interest in trying to find a solution to these current problems.

The goal is to find a methodology that can overcome the problem of the uniqueness of each individual project that makes it difficult to create a systemized tool that can work in multiple situations.

The increasing consumption of existing buildings with low energy efficiency and the correlated problem of climate change has directed our study more specifically on the renovation of the facades of **residential buildings**. The aim is to improve the performance of buildings as quickly as possible so as not to create disturbance in terms of visual, acoustic and health for the people who are near the area of interest.

The topic is of considerable interest to the European community so much so that this thesis was inspired by the **BIM4EEB** project "**Building Information Modeling For Energy-Efficient Buildings**" [64], a European initiative that intends to develop an open-source and interoperable platform, with a kit of specific tools, to optimize the decision-making process and asset management in the case of renovation of existing buildings (unlike the main BIM platforms developed so far, which are mainly aimed at the design of new buildings).

Figure 3.1_ BIM4EEB logo

BIM4EEB Project presentation - YouTube

The BIM management system - combined with the tools we will describe shortly - will also facilitate decision making and building management for the public and private sectors. This system will increase interoperability between the software and the stakeholders involved in the overall restructuring process.

Overall, **BIM4EEB targets** the reduction of least [64] :

> *20% of renovation time, 15% the average renovation cost, 10% of net primary energy use for a typical residential apartment and a reduction from 3 to 1.5 working days required for a deep energy audit.*

BIM4EEB will deliver an innovative BIM management system (**BIM4EEB BIMMS**) **six tools**, as follows [64] :

- **Tool 1 – BIM4EEB Fast Mapping of Buildings Toolkit**

  The BIM4EEB Fast Mapping Toolkit incorporates a range of new tools developed to speed up the scan-to-BIM process and to improve the data visualisation of an existing building by using Augmented Reality (AR). Architects, engineers, construction workers will be able to use the 3D digital representation to visualise the building including hidden elements inside walls such as wall studs, water pipes, and electrical ducts.

  1 BIM4EEB Fast Mapping of Buildings Toolkit - YouTube

- **Tool 2 – BIM4EEB BIMeaser tool**

  The BIM4EEB BIMeaser tool stands for BIM Early Stage Energy Scenario tool. The tool allows the assessment of several energy refurbishment design options enabling architects, engineers to provide solutions that best fit the client requirements while optimising the energy use and the indoor comfort for the occupants. As a result, the tool provides a comparative table on the different building renovation options in which aspects such as operational energy cost, the payback time of renovation, summer thermal comfort can be considered and validated in line with the Owner's Project Requirement.

  2 BIM4EEB BIMeaser tool - YouTube

- **Tool 3 – BIM4EEB BIM4Occupants tool**

  BIM4Occupants tool is a mobile application that provides residents and/or owners with information related to their building renovation activities performed. The collaborative and user-friendly web-based application consists of two main features. The first provides access to real-time and historical information about indoor and outdoor environment parameters (temperature, humidity, Illuminance, indoor air quality, energy consumption), the latter facilitates the communication between the building renovation team and flat residents and/or owners.

  3 BIM4EEB BIM4Occupant tool - YouTube

- **Tool 4 – BIM4EEB Auteras tool**

  Auteras supports building services designers to design Room Automation Systems (as part of Building Automation Control Systems-BACS) with a semi-automated process of a functional requirement survey and the generation of function block-based designs, which use standardised symbols to ensure a high comprehension from professionals in different trades. The resulting designs can be used directly to form bills of quantities for the procurement process. This tool imports and reads IFC information from existing buildings.

  4 BIM4EEB AUTERAS tool - YouTube

- **Tool 5 – BIM4EEB BIMcpd tool**

  BIMcpd stands for BIM Constraint Checking, Performance Analysis and Data Management. The tool is a user-friendly self-intuitive software suite designed to reduce processing time for constraint checking, increase building energy performance knowledge, standardise building energy data and help users to make informed and better decisions. It provides three main functionalities, the Constraint Checking Tool (identification of possible positions of ducts and cable runs, etc.), the Performance Evaluation Tool (information useful for the Measurement and Validation process) and the Data Management Tool (linking the information stored in different relational database management systems).

[5 BIM4EEB BIMCPD tool - YouTube]

- **Tool 6– BIM4EEB BIMPlanner tool**

  The BIMPlanner tool provides a digital environment to share up-to-date information about the plans and site progress operations with all participants of a renovation project. Applying the Location-based management system (LBMS) the tool links data from familiar planning and tracking desktop tools with BIM models to allow more effective management of renovation site operations. On a weekly basis, the user updates the ongoing tasks statuses, sets new tasks and shares new planning activity through the BIMplanner desktop or mobile application.

  [6 BIM4EEB BIMplanner tool - YouTube]

BIM4EEB BIMMS-BIM MANAGEMENT SYSTEM

The platform functions as a single source of information for the renovation project and provides a common environment for all BIM4EEB tools developed by the project.

All the figures involved are able to **work collaboratively in all phases of a building renovation project**, through a Common Data Environment (CDE) capable of storing and sharing data among users. Using different user profiles, the platform allows for example the inhabitants to control the data on their apartment, the designers to plan interventions using IFC models, the construction companies to plan their activities.

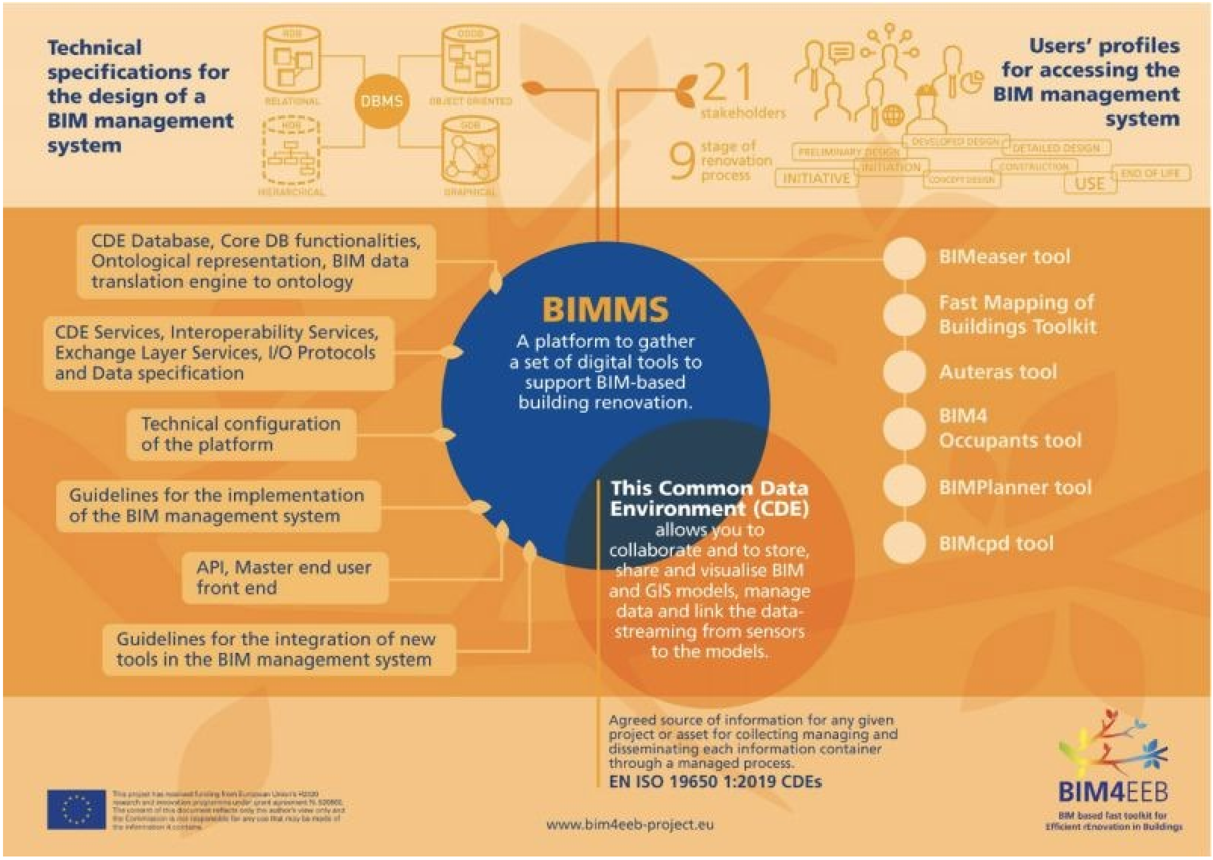


Figure 3.2_ BIM4EEB - BIMMS infographic

3.2 The Tool (What)

The tool we want to create aims to exploit the potential of some of the most famous and used software in the construction sector for the management of metadata (**BIM-based**), for parametric analysis (**parametric design**), for the production and management of spreadsheets accessible to all, by creating a bridge between them.

This would allow anyone to have full transparency of the progress that occurs during a project, eliminating clash problems that very frequently occur due to lack of communication between the parties.

Furthermore, everyone could work in the software on which he is most comfortable (within his competence) and then send (export) his updates to the other linked files: **the tool, therefore, wants to be sold as a platform (folder) within which contains several files coming from different software but having the same information inside them**.

Therefore, the tool wants to function as a **Decision Support System (DSS)** to facilitate the selection of the configuration that best meets the requirements set by the customer during the **Early Design Stage** and which will then be further investigated in the subsequent phases of the project.

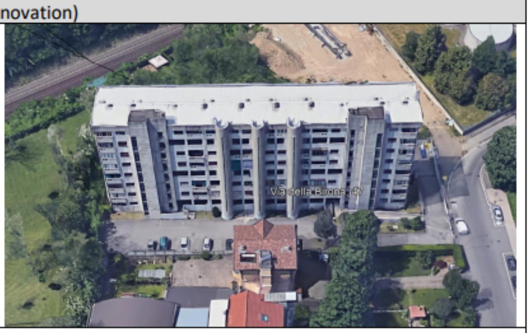
Demo Cases

European

Demonstration Site Italy

In this demonstration case, BIM4EEB partners applied BIM4EEB renovation methods.

<u>Technical Information</u>

Italian demonstration site	
Demonstration building (BIM4EEB methodology renovation)	
Building photo	
Location	Via della Birona 47, Monza (MB)
Use Category	Residential (Social Housing)
Building type	Building block (multipiano in linea)
Client	ALER
Flats Ownership (are the flats privately owned?)	ALER
Construction year	1981
Construction estimated value (euros)	€ 6.500.000,00
Renovation year (if any)	No renovation done before
Renovation estimated value (euros)	€ 7.500.000,00
Number of floors	8
Number of apartments	65
Total area (m2)	2.400
Energy rating	Classe G Ep > 3,5
Heating type	central
Elevator (Y/N)	Yes

<u>Expected Results</u>

Italian demonstration site

Tools to be tested	Measure of success
Tool 1 Digital tool for fast mapping of buildings	3.1 Time reduction on digital data acquisition >= 30%
	3.1 Time reduction on BIM model's creation >= 30%
Tool 2 BIM-assisted energy refurbishment assessment tool	1.4 Reduction on energy audit time >=50%
	1.5 Reduction of net primary energy use >= 10%
	2.2 Use of dynamic simulation tools for energy assessment >= 30%
	2.3 Integration of GIS data in BIM models for energy purpose
	3.3 Time reduction on decision making for different renovation scenarios >= 30%
Tool 3 Human-Machine interface tool	1.5 Reduction of net primary energy use >= 10%
	3.4 Deviation between predicted and real user occupancy schedules <=10%
	3.5 Reduction of net primary energy use >= 10%
Tool 4 Tool for connecting BIM models and BACS	1.3 Deviation between predicted and real thermal performance <= 10%
	3.2 Time reduction on BACS – requirements definition with users >=10%
Tool 5 Fast tracking tool for renovation operations	1.2 Reduction on renovation cost >= 15%
Management system	1.1 Reduction on renovation working time >= 20%
	2.4a Development of digital logbooks for renovated buildings
	2.4b Management of as-built data in "operational" BIM models

3.3 The Way (How)

To understand how to put what we have set into practice, we first thought about the output we wanted to obtain: a **multi-criteria diagram** that deals with the most important aspects to be taken into consideration when renovating a facade. What we expect is therefore a graph that combines the **various dimensions of BIM**:

- BIM 3D - GEOMETRY MODELING

- BIM 4D - TIME PROGRAMMING

- BIM 5D - ESTIMATE AND EVALUATION OF COSTS

- BIM 6D - PERFORMANCE ANALYSIS

- BIM 7D - THE OPERATIONAL MANAGEMENT OF THE BUILDING

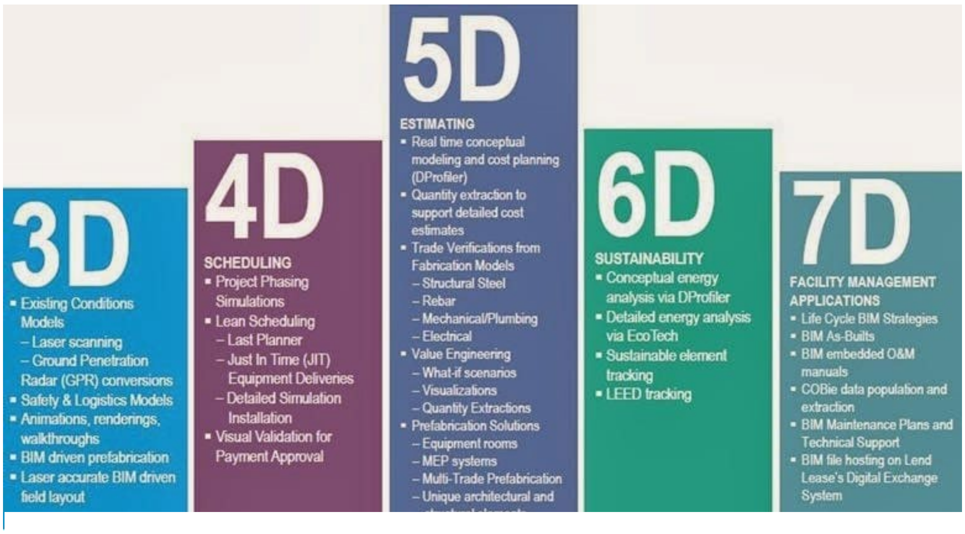


Figure 3.3_ The dimensions of BIM. Credits: www.cadlinesw.com

In fact, each dimension corresponds to the different macro-sets of typical aspects of the design which, if considered (and this is not always done), are often not placed in a reciprocal relationship between them. This approach, therefore, does not allow us to maintain a **holistic vision**, which really allows us to evaluate the pros and cons of each solution under different parameters of analysis.

For example, three-dimensional modelling, considered with respect to both any existing digital building models and the geometric description of the retrofit solution chosen, is not enough for a correct description of the entire system and stops at the simple 3D description. The management aspects of the different process times (Project Phasing Simulation, Lean Scheduling, etc.), which are usually accompanied by the cost evaluation aspects (Cost Planning, Quantity extraction, Value Engineering, etc.), add two dimensions to the design but they too fail to describe the aspects concerning the theme of Sustainability (energy analysis and LEED rating) and Facility Management (BIM models for future interventions).

Only through a **careful evaluation** of all these aspects and the creation of a graph for the attribution of **qualitative scores**, it is truly possible to have a global vision that can go beyond the individual considerations of each aspect. Being able to make **overall assessments** is therefore also useful to be able to identify any **correlations** between the quantities (as one quantity increases as the others change) and possibly pass to appropriate management of each according to the established **project limits**.

Related Projects

BIM4REN PROJECT

BIM4REN is an H2020 funded project involving 23 partners spread across 10 countries for a 4-year long series of developments on the topic of the exploitation of Building Information Modeling potential for the energy renovation of existing residential buildings. The objective is to introduce state-of-the-art and easy-to-use BIM tools and services in a single platform accessible to all construction professionals in order to increase renovation projects and improve collaboration across the whole construction value chain.

- Building Information Modelling based tools & technologies for fast and efficient RENovation of residential buildings | BIM4REN Project | H2020 | CORDIS | European Commission (europa. eu)
- Project - Bim4Ren

BIMERR PROJECT

Bimerr Project intends to design and develop a new toolkit to support renovation stakeholders during the renovation process of existing buildings, from concept to delivery. It should comprise of various tools (automated creation of enhanced building information models, renovation decision support system to aid the designer in exploring available renovation options, a process management tool which will optimize the design and on-site construction process, etc.). Everything is developed in an interoperable framework, in order to enable seamless BIM creation and information exchange among AEC stakeholders in an effort to enhance the rapid adoption of BIM in the renovation of the existing building stock in the EU countries.

- BIM-based holistic tools for Energy-driven Renovation of existing Residences | BIMERR Project | H2020 | CORDIS | European Commission (europa.eu)

SPHERE PROJECT

SPHERE is developing a unique, synchronized Building-centered Digital Twin environment based on Platform as a Service (PaaS). This will allow for the vertical integration of the processes' involving its design, manufacturing, construction and operation. During any phase of the building's lifecycle, the different stakeholder will be able to interact with this Digital Twin model, significantly helping in decision-making during each phase of the whole building's lifespan, increase collaboration and reduce inefficiencies, while improving energy efficiency and reducing time and costs.

- Project - Sphere (sphere-project.eu)

BIM-SPEED PROJECT

The BIM-Speed project was established to tackle these challenges by developing a combination of methodologies and tools with one central information source at its core: the Building Information Model (BIM), a digital representation of a building. This model will be the catalyst for a smarter, more efficient, method of deep renovation for the residential building sector.

- Harmonised Building Information Speedway for Energy-Efficient Renovation | BIM-SPEED Project | H2020 | CORDIS | European Commission (europa.eu)

4. METHODOLOGY

4.1 The Tool (Road Map)

The aim of what we aim to achieve is an adequate and **standardized test environment to predict the impact of design decisions on the renovation of multi-storey residential buildings,** rather than to provide a model of the building for each case.

This approach can in fact be advantageous on both the "customer" and the designer's side. The first can in fact set the requirements in terms of minimum and maximum performance on certain design aspects, even choosing which factors weigh more than others. The designers, on the other hand, once analyzes have been launched on each field involved, use these restrictive parameters to filter the solutions obtained between acceptable or not.

Everything will therefore be based on three-dimensional modelling performed using the Revit software, according to well-defined logic and criteria; this is in fact an excellent tool that allows you to easily manage both geometries and information.

We then plan to move on to the Rhinoceros/Grasshopper modelling space in order to carry out all that series of **analyzes** and considerations that the tool aims to deepen. Also, in this case, the choice of the software is not accidental, as it allows us to perform parametric analyzes based on the inputs provided, reconciling the accuracy of the results and the possibility of modification at any time.

Here the various analyzes will be developed (geometric, energetic, structural discretization, times, costs) to provide decision-making support to the designers. Everything is then collected in a **single final diagram** that allows you to bring together the different aspects of the design and to **compare the different scores obtained**, in order to evaluate the design choice from every point of view, as well as identify which of the proposed solutions meets the set requirements better.

As the last step of this process, we plan to return to the BIM environment with the bake of the solutions we have chosen.

The process we followed and the software we used during our study is represented in the diagram on the next page. Furthermore, we show an overview of the Grasshopper script in which the most important steps of our analysis were carried out.

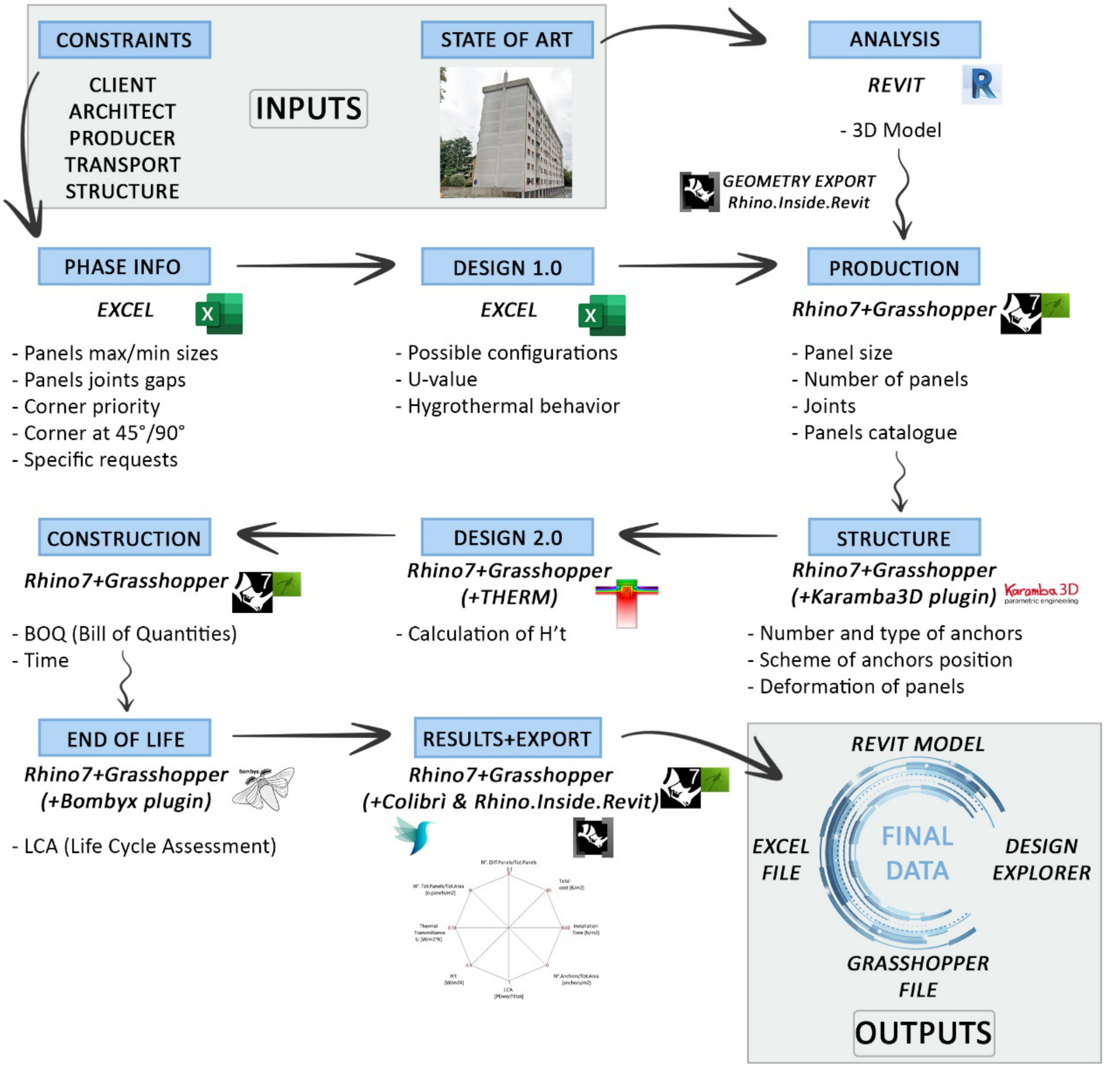


Figure 4.2_ Road map of our analysis.

LEGEND:

1. Export from Revit
2. Geometry definition (Preparation of the geometry, Panelization, Extrusion)
3. Calculation of areas and linear thermal transmittance
4. Energy 2.0 (H't)
5. LCA
6. Time and Costs

7-1./7-2. Print to Excel

8. Panels catalogue
9. Export to Revit
10. N°. Anchors and Panel deformation
11. Results: Spider diagrams

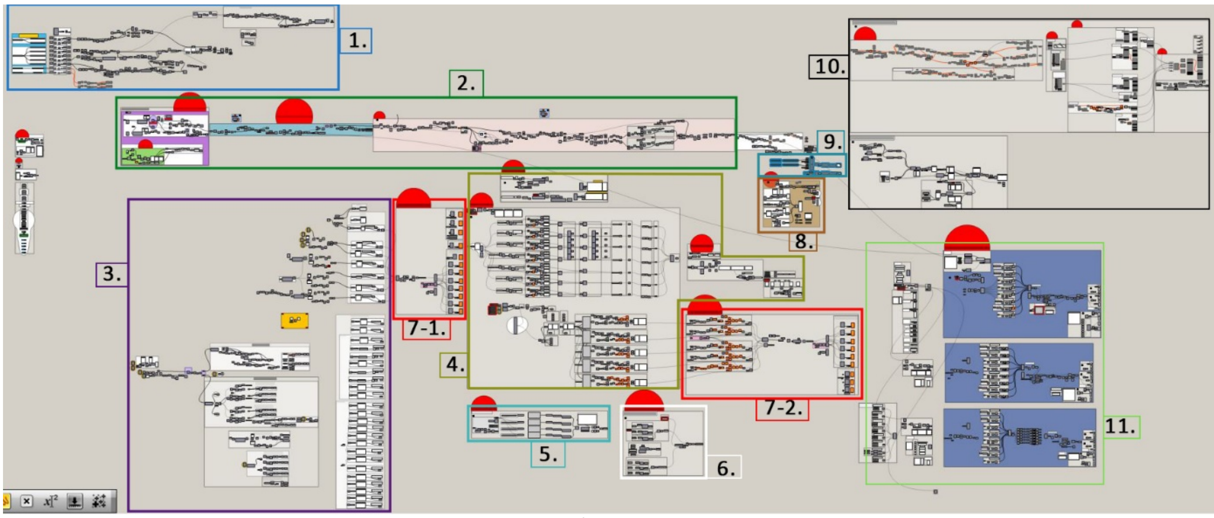


Figure 4.1_ Grasshopper script overview.

4.2 Revit file

3D Model Definition

CHAPTER'S SUMMARY:

The pre-design analysis tool has as its ultimate objective the application on a **real building** to support the decision-making phase of the intervention; it is not possible to think of validating the goodness of what is produced without first testing it on a practical case. It is however true that before reaching this result, various **development phases** were followed, which involved the realization of intermediate steps on increasingly complex geometries, in parallel to the articulation of the visual programming phases.

The main steps are explained below, but basically, the progression was:

1. **Single opaque facade** with a finite number of windows. The first studies have been advanced on a possible decomposition into regular-shaped elements, which would respond to input parameters defined by the user as well as to dimensional constraints.
2. **A typical building** consisting of n floors with perfectly regular opaque closures. The studies carried out on the single facade have been taken to a higher level considering the presence of several two-dimensional facades on different geographic orientations (NSEW); another addition that has been made is to consider glass openings of regular rectangular shape but of functions (windows, French-doors) and variable dimensions. Obviously, our intentions were to understand how far we could push ourselves and if (and what) limits we would encounter as the script proceeded to the next stages and in complexity.
3. **Case study** with shapes, geometries and dimensions that respond to a particular constructive logic, namely that of a multi-story residential building built in the second half of the twentieth century. At the time this phase was carried out, a Revit model of the state of art complete with structures, closures and finishes was not available, but extensive documentation was provided in the form of 2D drawings of all the interesting floors. it was therefore necessary to model a building as faithful to the original as possible based on the indications found in the project tables in .pdf format.

Below we will then proceed to analyse as careful as possible all the steps briefly mentioned above.

2D Modeling – Rhino

To understand how to best set up a subdivision that was repetitive and at the same time describable by mathematical logic, we referred to the available literature [65] and in particular to the method for the **recursive generation** of surfaces that approximate the points lying on a mesh of arbitrary topology (**Catmull-Clark**) [66].

The method is presented as a generalization of a subdivision algorithm (bicubic and recursive) of B-spline patches. If a spline function of order n is a piecewise polynomial function of degree n-1 in a variable x (the points where these pieces meet are known as nodes), B-spline functions can have their continuous derivatives, according to the multiplicity of nodes [67].

Such methods arose well before the advent of Computer-Aided Design (CAD) and the need to translate these geometries into geometries suitable for large-scale analysis, mesh and input for FEA (Finite Element Analysis) codes; however, this task is far from trivial today and for complex engineering projects it is now estimated that it now takes over 80% of the overall analysis time, and projects are becoming more and more complex.

In an estimation of the relative time costs of each component of the model generation and analysis process at Sandia National Laboratories, it has been found out that the model building process completely dominates the time taken to perform the analysis.

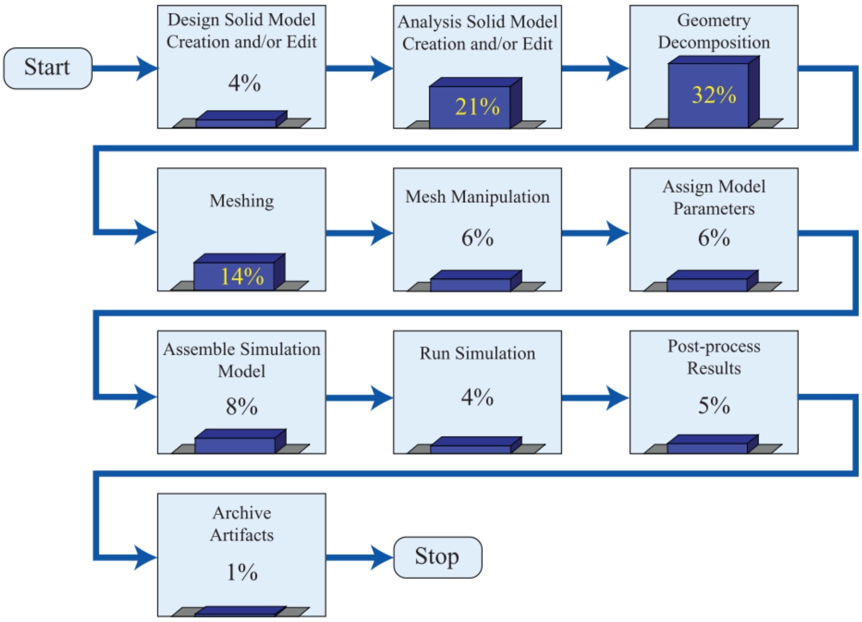


Figure 4.3_ % Commitment of each design phase of the project.
Credits: Michael Hardwick and Robert Clay, Sandia National Laboratories

Recursive patch splitting algorithms have been widely used in computer graphics since Ed Catmull (then CEO of Pixar) and Jim Clark (founder of Silicon Graphics and Netscape) first devised them for rendering shaded patch images. of the curved surface in the late seventies [65].

The **basis of the method** results [66] from the consideration of a B-spline patch on a rectangular mesh of the control point. The shape of this patch is governed by 16 control points, as shown in the figure below (the original points are circled). By dividing this patch into 4 sub-patches, 25 sub-control points are generated. These are indicated in the figure by X_s. Note that some of the X'_s are in the middle of the original mesh squares and this is called new face points. Likewise, some of the new points lie on the edges connecting the original control points; these are

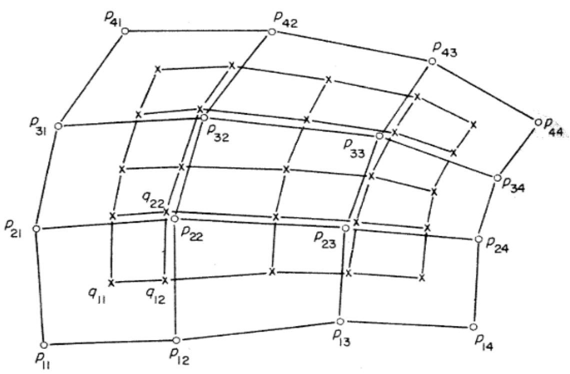


Figure 4.4_ Standard bicubic B-spline patch on a rectangular control-point mesh.
Credits: Recursively generated B-spline surfaces on arbitrary topological meshes

called new edge points. The points corresponding to the old control points are called new vertex points. In splitting the original patch, it turns out that each new control point of a given type is calculated from its adjacent points by the same form of algebraic expression. For example, new face points are calculated as the average of the four old vertices that define the face.

For the study of the problem, we concentrated on a generic opaque surface (size 16.00 m x 3.00 m) inside which three windows (height from the ground equal to 1.00 m) were positioned, one with dimensions 2.50x1.50 m and the remaining two dimensions equal to 2.00x1.50 m.

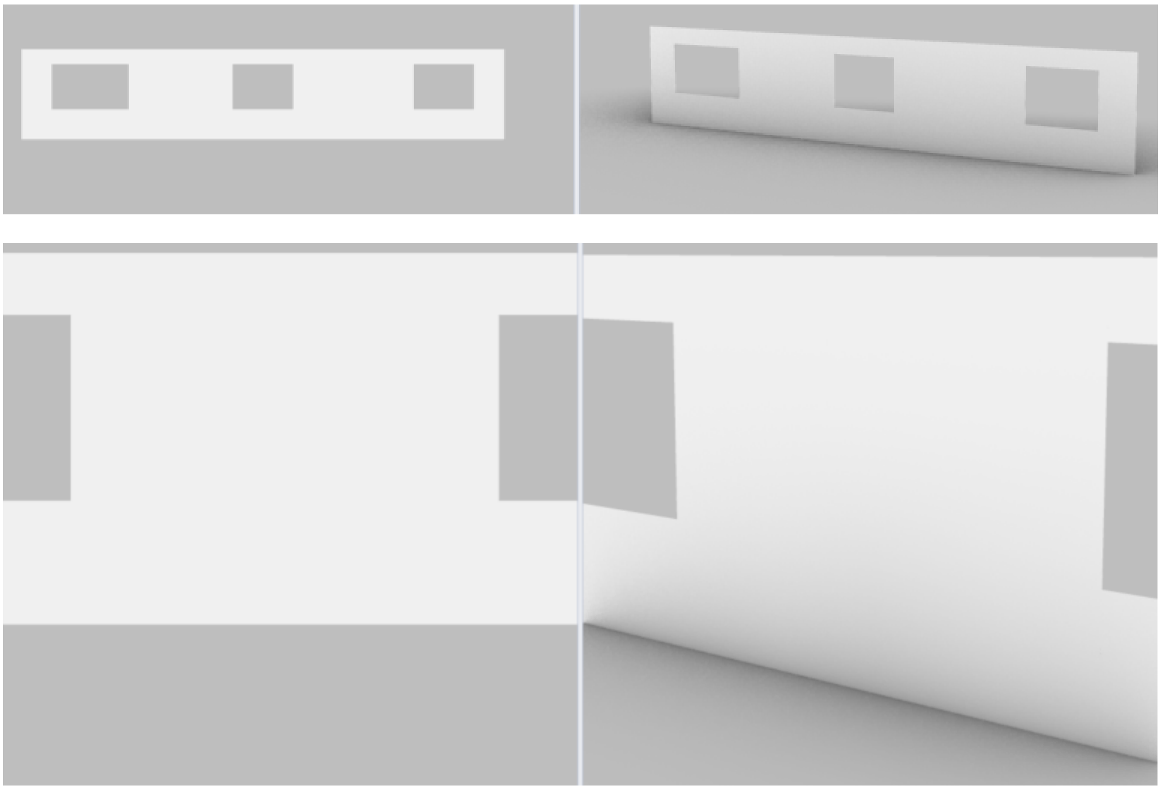


Figure 4.5_ Test opaque Surface

The focus that has been made concerns the portions of the continuous façade between two windows, even if the steps described are valid for each generic surface identified; the simplification was however made to take into account two different areas (panels between windows and panels above-below the window) which will have to meet different geometric requirements/assembly/etc.

Focusing on one of these surfaces and applying the Catmull-Clark process just described we would obtain:

step = 1

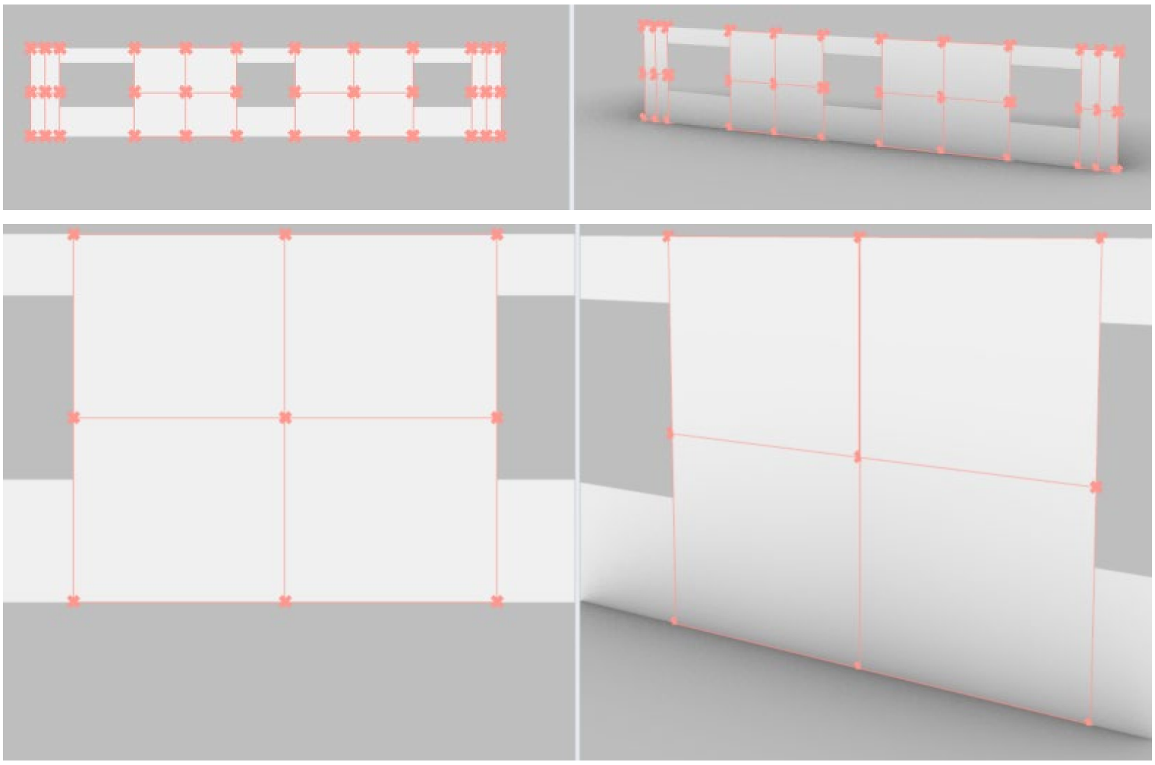


Figure 4.6_ Test opaque Surface - step 1

step = 2

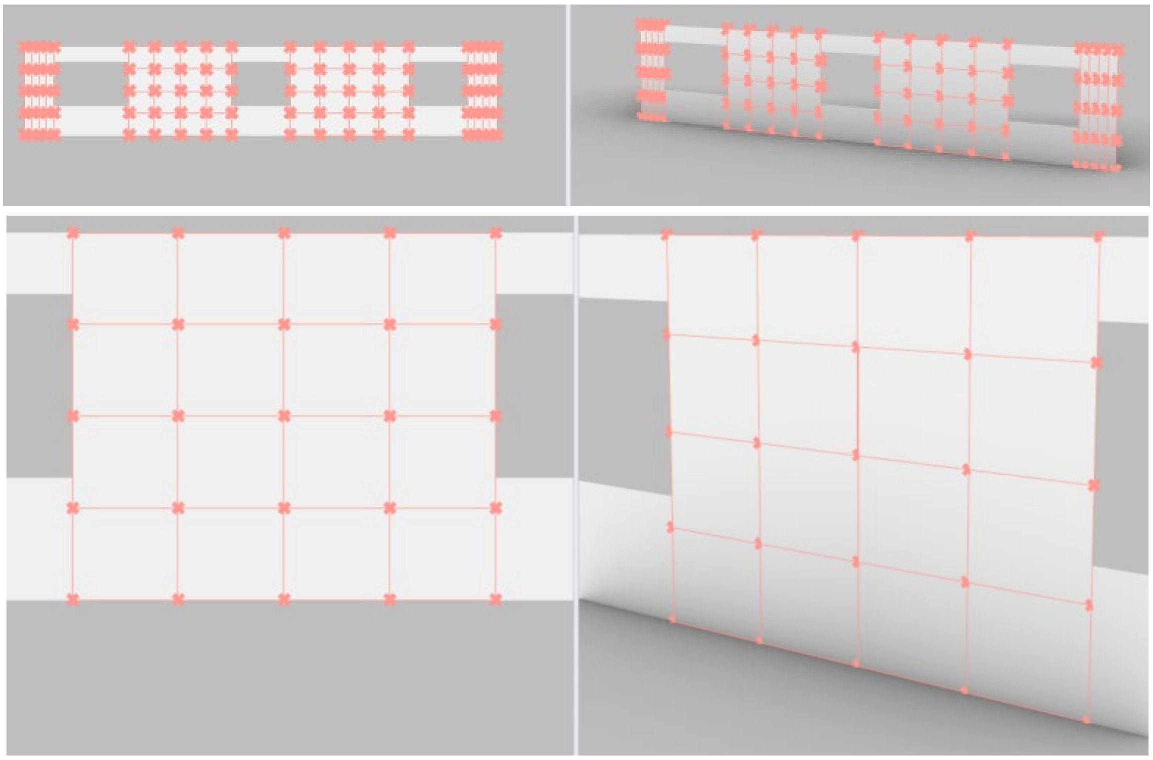


Figure 4.7_ Test opaque Surface - step 2

and so on…

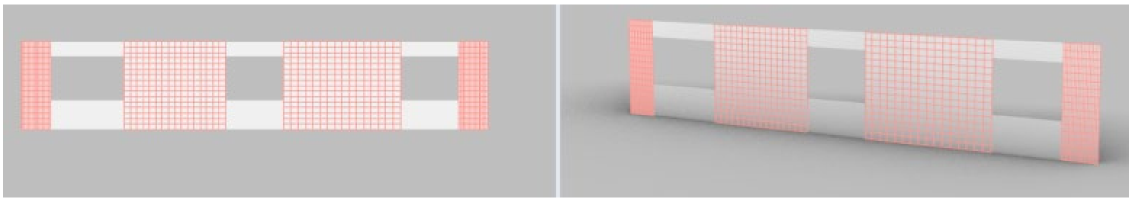


Figure 4.8_ Test opaque Surface - step n

Although by its nature it can be repeated an infinite number of times, the application of constraints by the user allows considering all those dimensional and production requirements that make it impossible to go below a certain lower limit value. Conceptually different is the application of higher limits to the geometry of the single facade, which allows having indications on which is accessing the imposed constraints (structural, transport, producer, etc.) and thus proceed to its decomposition.

By combining the potential of the geometric process with those of parameterization and data management of software such as Grasshopper, it is, therefore, possible to choose which configuration to apply on every single portion of the facade, among those that fall within the domain of acceptability.

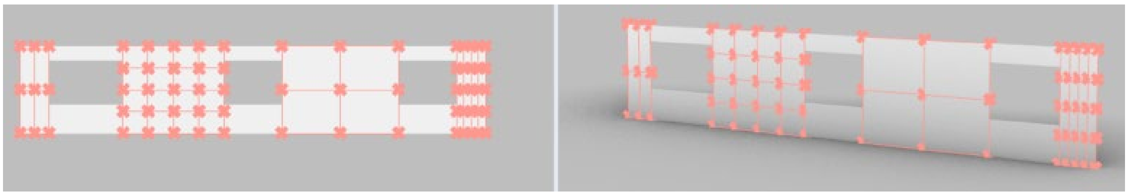


Figure 4.9_ Test opaque Surface - desired subdivision

3D Modeling - Rhino

The next step was to bring the concepts just seen into the three dimensions of space, considering a geometry that is still simple, but which already presented all the most interesting aspects of a real panelling phase: multi-story building, facades on the four cardinal axes and presence of openings with the irregular distribution.

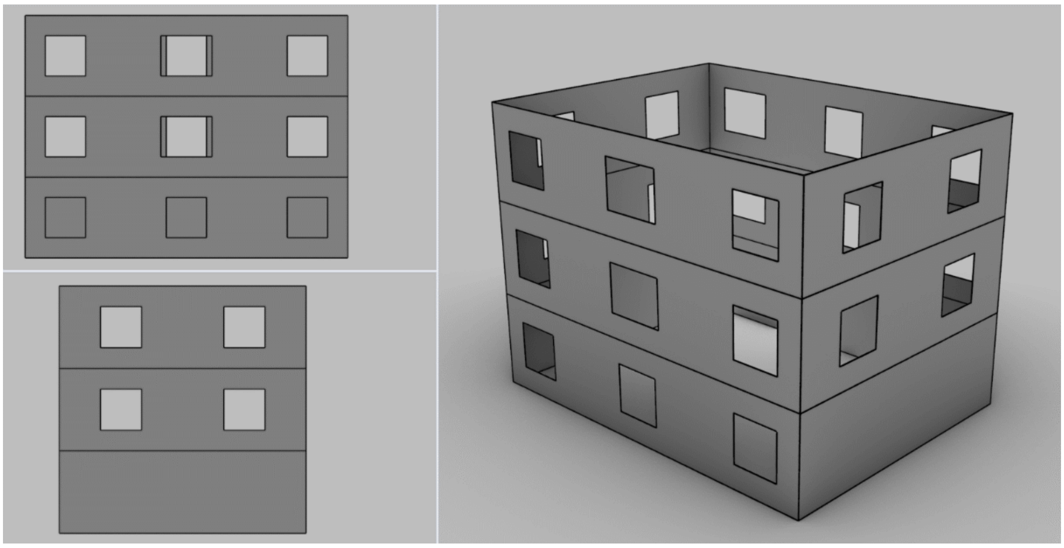


Figure 4.10_ 3D Model

The concepts of recursive subdivision seen in the previous chapter have been resumed but adapted according to a subdivision no longer by midpoints (Catmull-Clark) but in **n segments of the same size**; this was necessary to increase the size of the pool of acceptable solutions, also following a limitation of the maximum and minimum size of each element.

A numerical **example** that we can do to clarify the concept is the following: let us imagine we take a wall 4 m long and 3 m high without openings and that the dimensional constraints are only on the width that must be in the range (0.3, 2); according to the **subdivision shown in the previous chapter** we would have:

step 0 -> 1x 4 m wide panel

step 1 -> 2x 2 m wide panel

step 2 -> 4x panel 1 m wide

step 3 -> 8x panel with a width of 0.5 m

step 4 -> 16x panel with a width of 0.25 m

stopping at the fourth iteration to stay within the acceptable range (four different panel configurations).

If, on the other hand, we assumed to **divide the width of the panel into n equal segments**, we would have:

step 0 -> 1x 4 m wide panel

step 1 -> 2x 2 m wide panel

step 2 -> 3x panel of 1.33 m width

step 3 -> 4x panel of 1.00 m width

step 4 -> 5x panel with a width of 0.8 m

step 5 -> 6x panel of width 0.67 m

step 6 -> 7x panel with a width of 0.57 m

step 7 -> 8x panel with a width of 0.5 m

step 8 -> 9x panel of width 0.44 m

step 9 -> 10x panel with a width of 0.40 m

step 10 -> 11x panel with a width of 0.36 m

step 11 -> 12x panel with a width of 0.33 m

step 12 -> 13x panel with a width of 0.31 m

step 13 -> 14x panel with a width of 0.29 m

thus, guaranteeing us thirteen possible configurations to test, nine more than the previous schematization. A separate consideration concerns the fact that the panels have been designed and tested with an **inter-floor height**, also and above all for technological reasons: the possibility of anchoring to the load-bearing frame of the existing structure is in fact one of the most used and conceptually simpler techniques to achieve. For this reason, it was decided to opt for this solution without going into invasive procedures that did not constitute the focus of the thesis. **Please refer to the Geometry Definition chapter for further information on the panelling process.**

Based on the dimensions of each element, therefore, also in order to have a simpler global reading, these have been grouped into families called types; they have been represented graphically by means of a colour gradient where the same colour corresponds to the same family (and therefore the same dimensions).

An important novelty compared to the previous version was the introduction of a catalogue that attributed a specific label to each piece. Having added some additional complexities to the previous model (number of floors and orientation of each face) it was, in fact, possible to analyze and classify each element according to its own peculiarities, i.e., based on orientation, type of belonging, floor number and progressive number.

In the end, the results obtained were more than satisfactory and formed the basis for the last and true modelling step, which we are now going to describe.

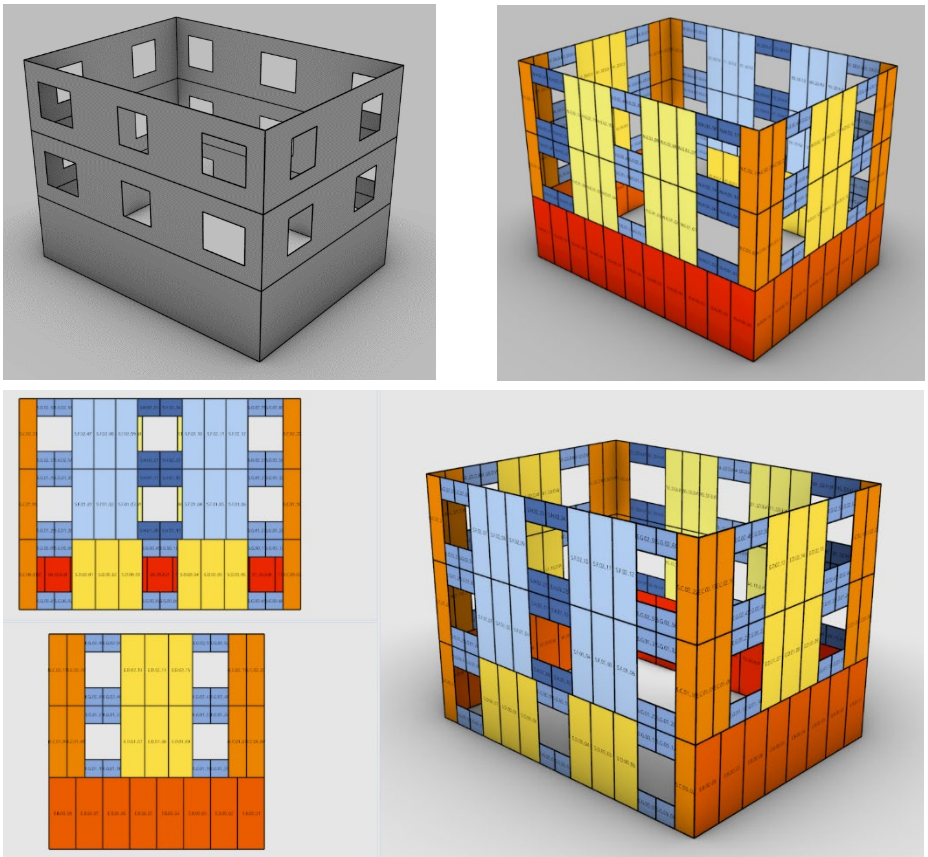


Figure 4.11_ 3D Model- Panelization

3D Modeling – Revit (case study)

We then went on to consider a three-dimensional model of a real case study **assumed as a reference model for all the following discussion**. The construction is a building of 65 lodgings in the Municipality of Monza, Via della Birona 47 which was subject to Extraordinary Maintenance in May 2019 by ALER (*Azienda Lombarda per l'Edilizia Residenziale*). As we said, at the time we started this design phase, a complete Revit model was not available to rely on, therefore we have personally committed ourselves to create a model representative of the state of affairs deductible from the plans provided. When the 3D model came out, some problems have emerged that have guided the subsequent design choices. *The script works, but it is unlikely to think that at the moment it is able to manage all the .rvt models.* The reasons lie in the fact that each building is in fact very different from the others (irregularities, overhangs, openings) and that each model is calibrated on the basis of the objectives that the designer has set himself to achieve. This is to say that **we had a reference model that came directly from the designer but that it was not possible to use it directly as a basis for all the following studies**. However, it was possible to use it as a reference when we created a parallel "*simplified*" version that could be read by the software; the version was obviously created in the most accurate way possible so that any deviations from the original model did not correspond to distortions in the results and so it is legitimate to think since the applied concepts are the same. **However, the concept remains the same, we start from a Revit model supplied by third parties and built according to precise logic**.

The resulting model is therefore characterized by:

- dimensions in plan equal to 65.0 x 12.0 m.
- 8 floors of 3.0 m each for a total height of 24.0 m.
- structural grid composed of pillars and beams in reinforced concrete.
- floor area = 800.0 m^2 approx.
- the gross surface area of the envelope = 5800.0 m^2.

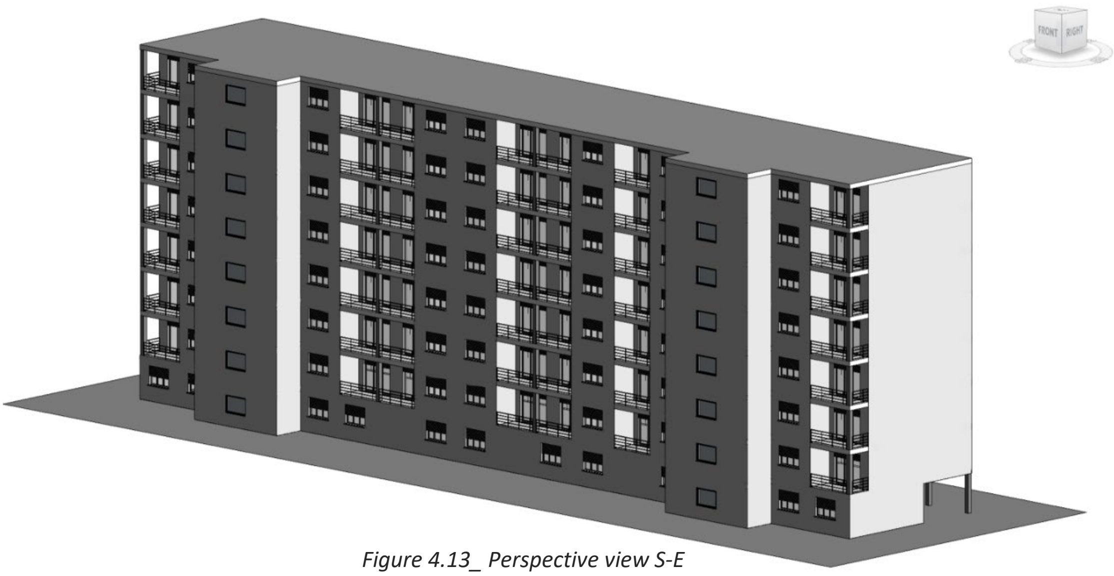


Figure 4.13_ Perspective view S-E

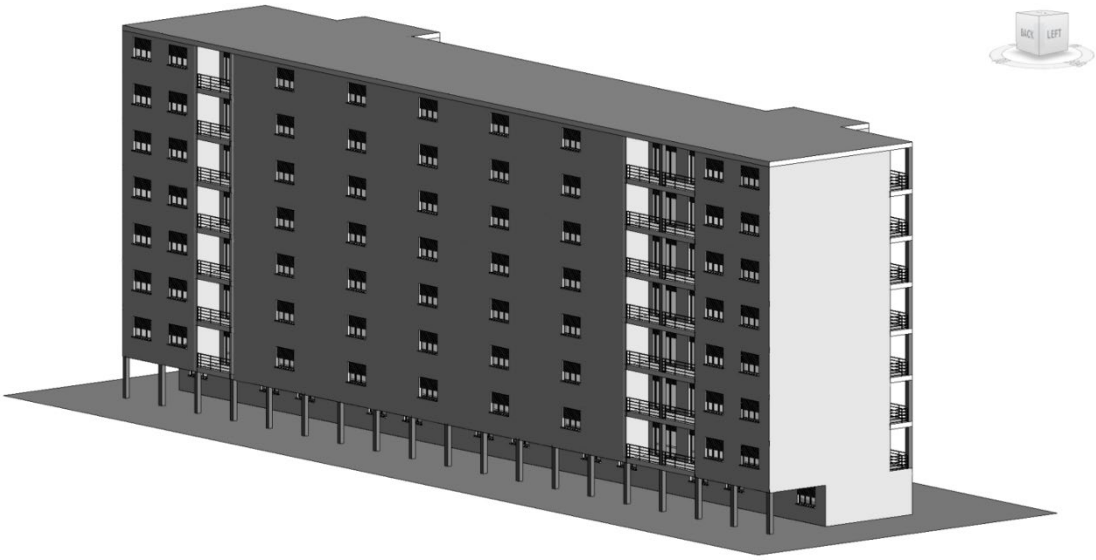


Figure 4.121_Perspective view N-W

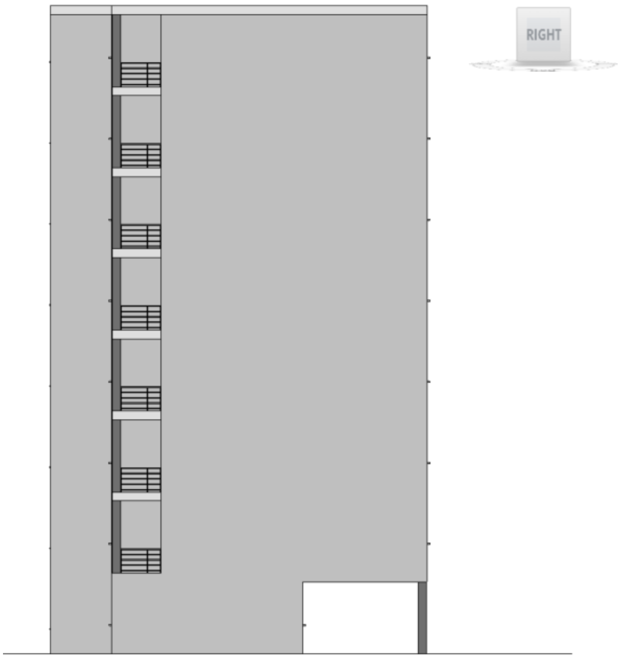


Figure 4.154_ Elevation view E

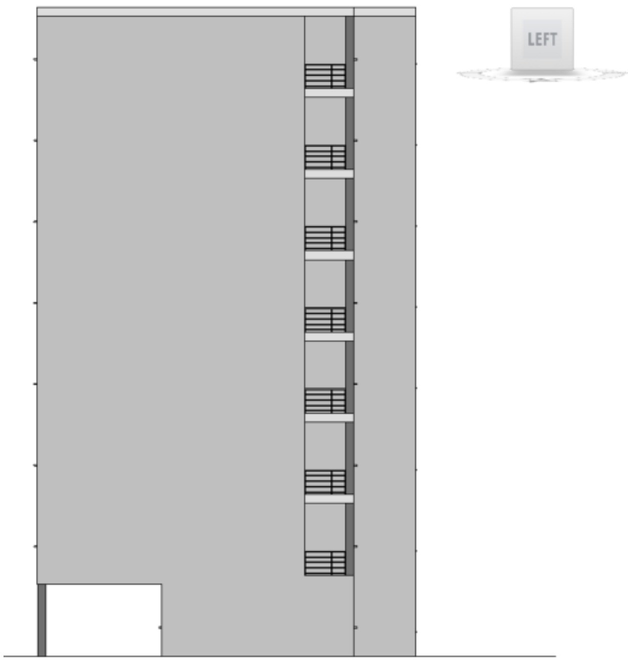


Figure 4.15_ Elevation view W

Figure 4.14_ Elevation view S

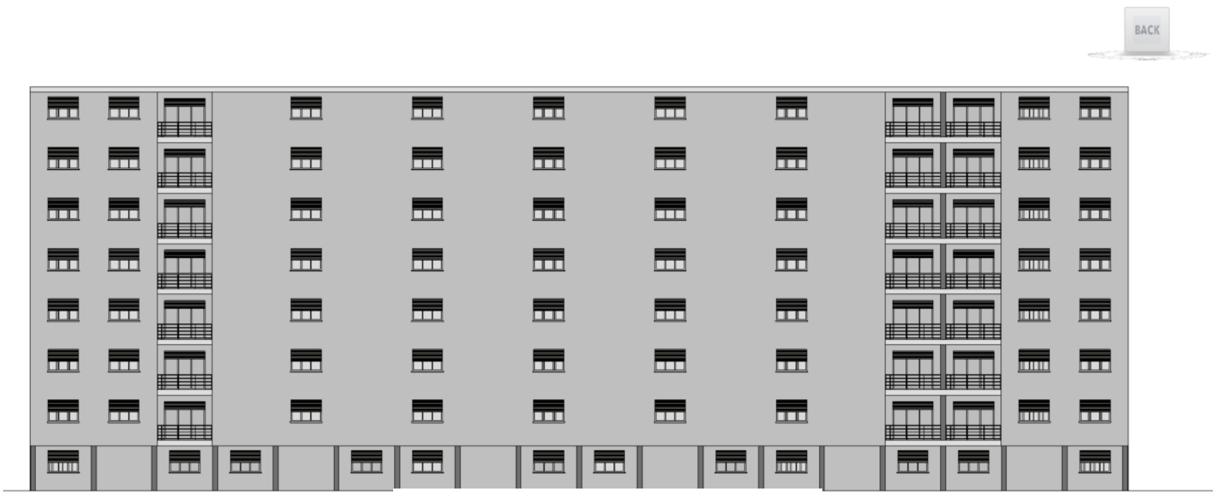


Figure 4.12_ Elevation view N

Figure 4.16_ Camera - S

Figure 4.17_ Perspective view - External terrace

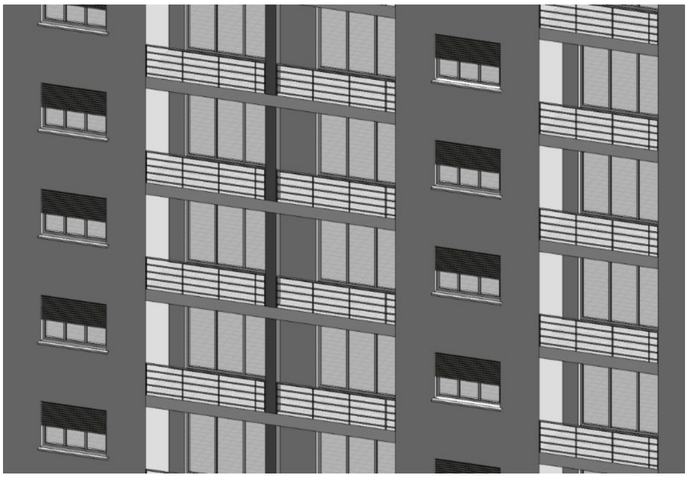


Figure 4.18_ Perspective view – Internal terrace

The advantage compared to the two steps described above is certainly enormous. The biggest is certainly the fact that modelling is taking place in **one of the most widespread environments** at the engineering level and beyond, that is **BIM**; the possibility of having a large number of models from which to draw shapes and geometries, as well as the possibility of dialogue with as many subjects as possible certainly represents an enormous potential; we don't think it needs to be said that geometric modelling in other environments such as Rhino cannot be as effective and useful for all the problems this software entails. The amount of information, as well as the extensive management skills on geometries, are in fact the real advantages of all that part of the construction world that tries to investigate all other aspects proper to design, a goal that this thesis has set itself from the beginning.

Export from Revit

CHAPTER'S SUMMARY:

We then move on to the phase of importing the model from **Revit** (BIM) environment to that of parametric geometric modeling offered by the combination of **Rhinoceros** and **Grasshopper**. **Rhino.Inside.Revit** has been used because it is one of the most interesting projects in this area and allows you to establish a continuous dialogue between the two software. Precise rules must be established in order not to generate errors.

The growing need to make *Rhinoceros* and *Revit* communicate has increased the demand for a bridge between them and over the years various solutions have followed one another (*BIM GeomGym IFC*, *Grevit*, *VisualARQ*, etc.). They certainly deserve the merit of having explored and consolidated a procedure that was not nor fluid or stable, passing through the IFC (Industry Foundation Classes) data exchange format, which since 1994 has in fact constituted the most used way for interoperability.

In recent months, **Rhino.Inside.Revit**, the ambitious project by **Robert McNeel & Associates** which aims to allow embedding Rhino 7 into other applications, has increasingly taken up space.

But what is Rhino.Inside.Revit? As they say, it is:

> *Rhino.Inside.Revit is one of the Rhino.Inside's most exciting projects. It is an addon for Autodesk Revit® that allows Rhino 7 to be loaded into the memory of Revit just like other Revit add-ons. Rhino.Inside.Revit brings the power of Rhino 7 and Grasshopper to the Autodesk Revit® environment.*

The program runs on the latest version of Rhinoceros 7, incorporated and recalled from the Additional Components tab of Autodesk Revit v. 2019/2020/2021; without going through an IFC file, the company has developed a direct dialogue, allowing the creation in real-time (with instant preview) of BIM models in Revit through inputs provided in Rhinoceros. We can say without a doubt that the innovations introduced in this field are enormous and being that many parts are still in Work in Progress, surely the addon will improve more and more by incorporating new functions and improving those already existing.

At present, however, the project is operational and allows us to carry out most of the actions we had set ourselves up and for this reason, it was chosen over the other programs we had mentioned earlier.

The strength of the software is to be able to read not so much the geometries of the Revit model - which is still possible - as the attributes of those elements. It is, in fact, possible to filter the whole model based on the match with the selected **Element Type**, being part of a specific **Model Categories**; the output is, therefore, the possibility to select each type separately

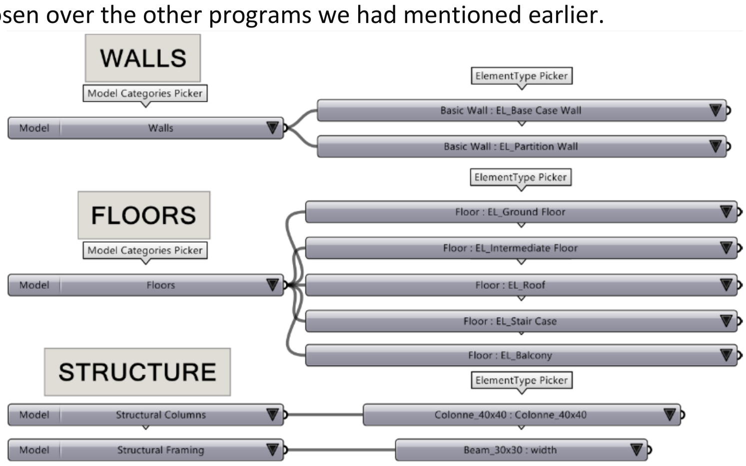


Figure 4.19_ Selection of the ElementType Picker to import from Revit.

in Revit which, through a specific component, is converted into 3D geometry on Rhinoceros, effectively losing all the information that is not specific to this software. This opens horizons in the design field, making the selection easy and immediate as well as the import of multiple families at the same time with an instant check of what is selected.

These great advantages are in fact also the real only big limitation of this type of design that requires the exact knowledge of the name of the type of what you want to export; it is therefore not possible that the designer's desire to export all the opaque facades corresponds to full automatism in the software without first entering the name that these facades have within the Revit model.

Obviously, this implies **a long series of problems**.

First, the fact that there is often **no uniformity in three-dimensional modelling** on Revit: each designer, based on the objective set and the degree of precision that he intends to pursue, basically models as he pleases. Just think, in the case of facades, of all the reciprocal positions that a wall can have with respect to the floor, beam, etc., or whether these two elements can be joined or not, and so on; all these considerations, which at first sight may seem trivial, heavily influence the creation of the model and its general organization. If each designer then elaborates his own model with standards, families, types, etc. different, it is difficult to think of being able to find a common thread that allows obtaining the same final output.

To overcome this problem, **new families have been created** for the tool we are proposing, marked with the letters **EL (Enna -Lencioni)**, in order to keep track of them more easily. In the short future, however, it is not excluded - and indeed it is hoped - that the theme of standardization of Revit models will be increasingly studied, otherwise it will be necessary to set a precise coding (purely related to this tool) to correctly manage the import of the various elements.

In any case, the **main steps** we have decided to follow are listed below.

1. **Selection of the correct Model Category among the many available.**
2. **Select the Element Type picker you want to import.**
3. **The first Check has been introduced to avoid that a possible error in the selection causes the script to crash suddenly.**
4. **Components: specific selection (Type Filter) + extraction of 3D geometry (Element Geometry).**
5. **The second Check to verify that the imported 3D shapes are the ones wanted.**

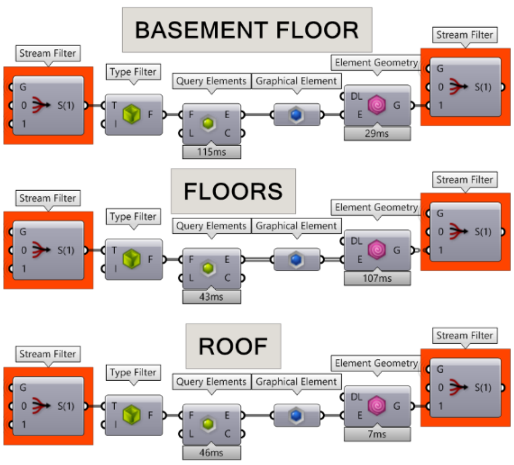


Figure 4.20_ In red the step3 "First Check"(left), the step4 (centre), in red the step5 "Second Check" (right).

At the same time, a similar approach was also used for importing the Levels - without having problems with the names - from which the Elevations of the various floors (m) were deduced, useful many times during the script settings.

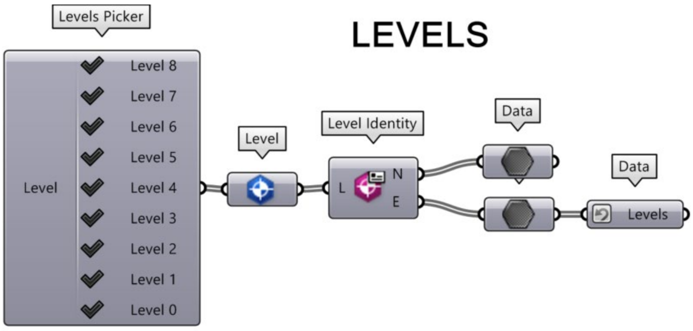


Figure 4.21_ Levels import.

At the present time, therefore, the model looks like this:

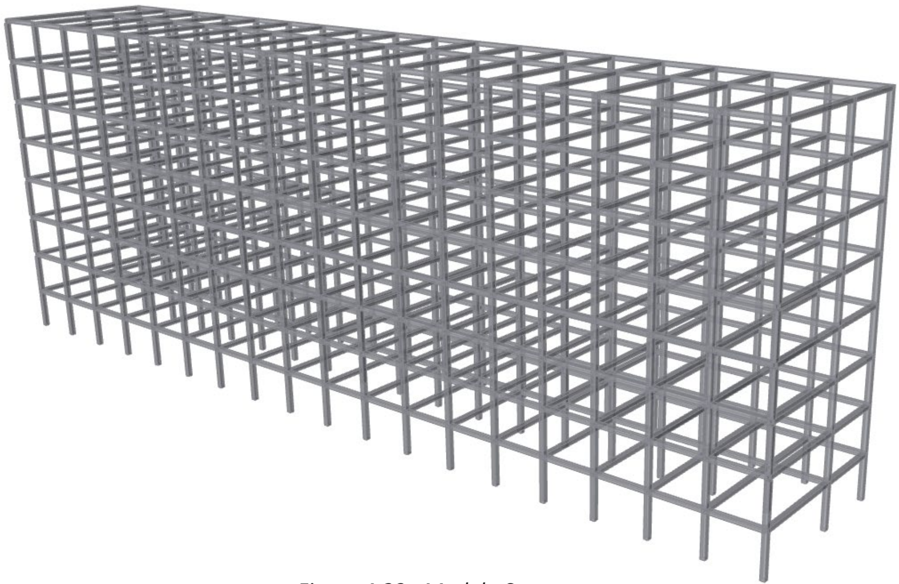


Figure 4.23_ Model - Structure.

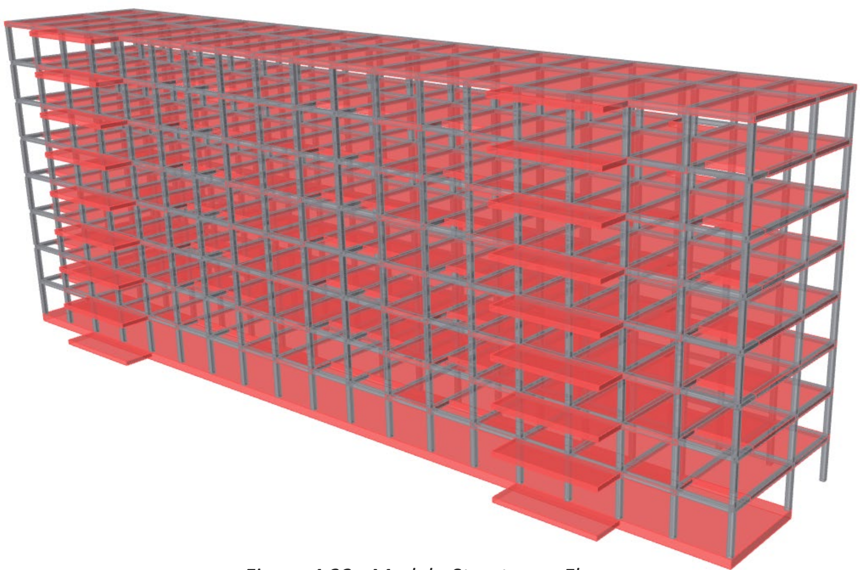


Figure 4.22_ Model - Structure + Floor.

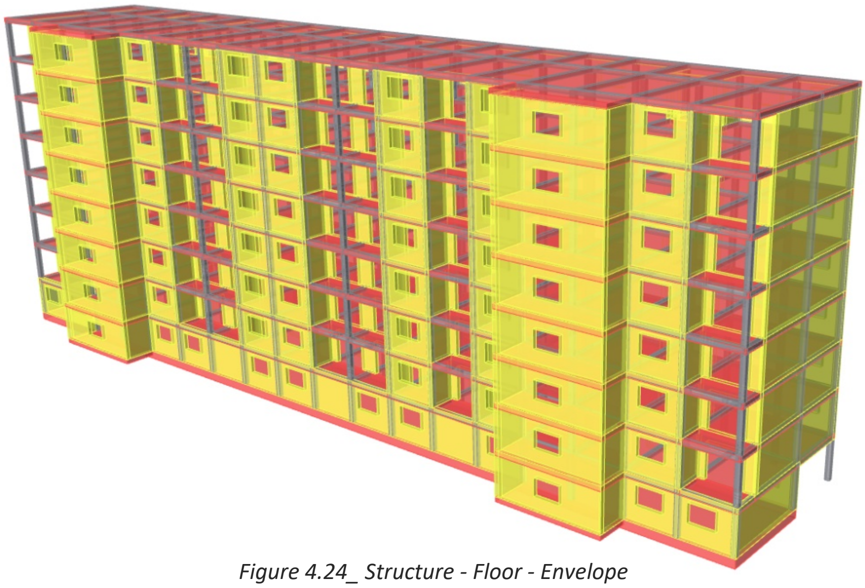


Figure 4.24_ Structure - Floor - Envelope

but it was necessary to elaborate these forms in more detail before proceeding with the subsequent phases of analysis. In fact, if on a general level the model is presented as geometrically complete, it presents errors on the surfaces that delimit it in the corners. Being geometries imported from Revit, these parallelepipeds follow all the rules of this software, including the priorities of one wall over the other. This is geometrically reflected in the presence of holes between one wall and the contiguous one, which makes the face discontinuous and unusable.

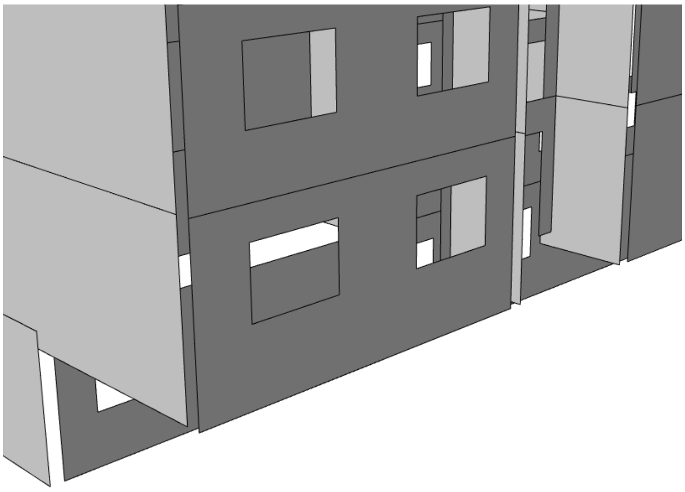


Figure 4.25_ Corners not matching.

We, therefore, opted for a different approach, that is, starting from the geometries of six inter-story floors. These floors (residential and stairwells) were deconstructed to define the ***external intervention perimeter***, which was in turn transformed into a surface using the loft command and then in a unique ***solid extrusion***.

This procedure allows us to solve the problems related to the spaces left by two walls in contact but leaves open a long series of ***problems*** that we have tried to mention before. In this case, it has been chosen to refer to the external perimeter of the intermediate floor slabs, but there is no need to remember that the choice is not totally true. From the constructive point of view, on the perimeter there should be a system of load-bearing beams with double warping, in which the floors are inserted; there is, therefore, a problem in the management of overlaps.

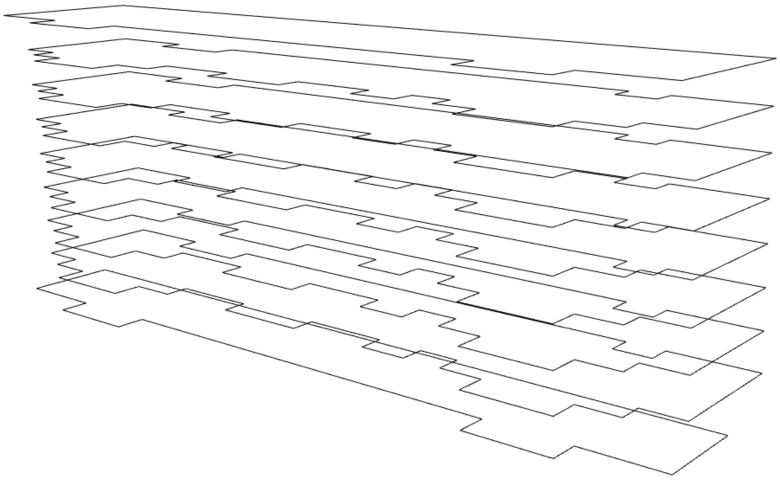


Figure 4.26_ External intervention perimeter

Should we, therefore, refer to beams only perimeter beams? Yes and no. How to automate the various procedures in the case of stairwells consisting of reinforced concrete partitions? The matter becomes more complicated.

We must conclude by saying that the problem has been encountered and therefore studied and resolved in the manner deemed most appropriate. It is certainly not the only one, as the various configurations that could arise when we pass from one model to another are not unique.

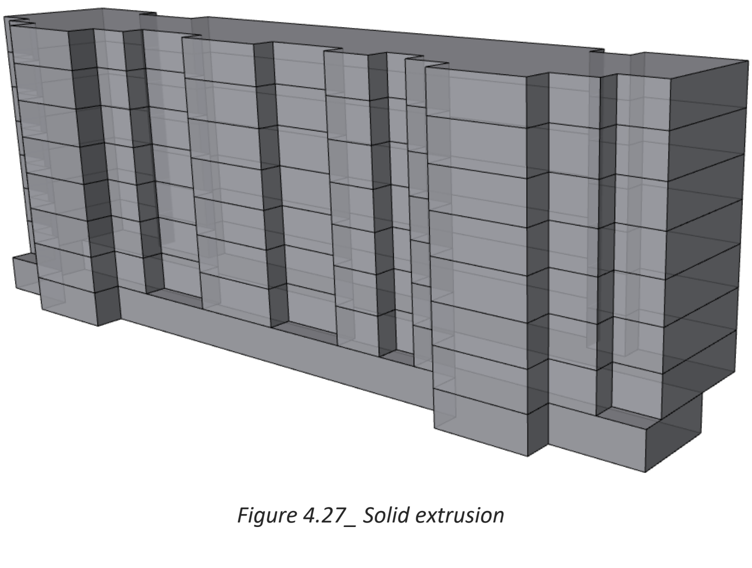


Figure 4.27_ Solid extrusion

The next step concerns the ***management of the geometries*** thus created. Geometric modelling software, whether for architectural or structural applications, assigns a set of three coordinates **(*x, y, z*)** to each one-dimensional or two-dimensional element. These vectors in space have direction and versor as a direct consequence of the modelling that has been done, with rules that recall the "right-hand rule": even a small error in the modelling, therefore, involves a reversal of direction or worse.

To avoid these problems, it is, therefore, necessary to immediately pay attention to how the wall surfaces are generated, to give an example relevant to our case. Since the import from Revit takes place smoothly but not without problems or precise considerations, it was decided to post this checking phase and possible correction after the generation of the surfaces. The rule we followed is that right hand, considering that:

- the local axis x lay simultaneously in the facade plane and in the horizontal plane and that its direction followed an anticlockwise path.

- the local y-axis coincided with the global z-axis but with the direction pointing upwards.

- the resulting local z-axis therefore lies in the horizontal plane and is perpendicular to the facade surface, its direction *always points outwards*.

The steps described above take place automatically, so whatever the triad (x, y, z) the output will always be a correctly oriented surface. This unique convention allows us to proceed with the subsequent steps which strongly depend on the main axes of the surface and which otherwise could not work.

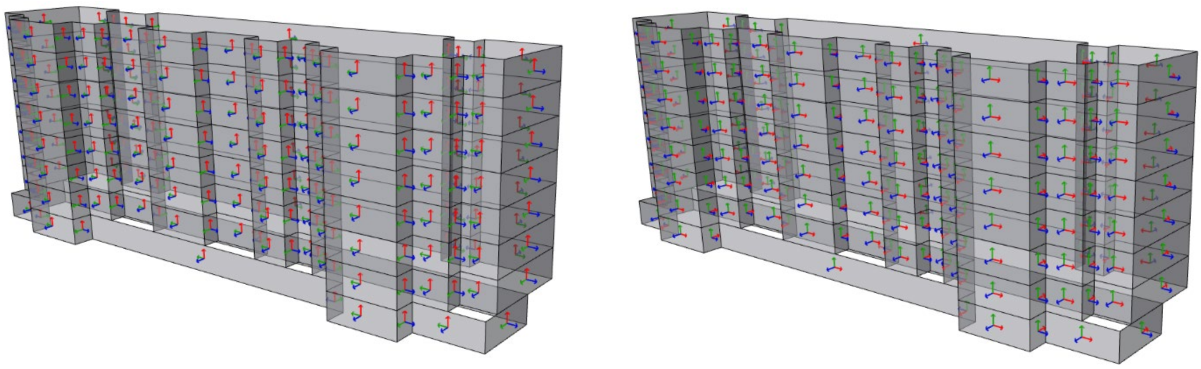


Figure 4.28_ Surface Axis - before (left) and after (right)

Separate consideration must be made on the portions of the building that have terraces.

If the possibility of intervention with ETICS systems or prefabricated panels (EASEE / TES) has been evaluated for the building, ***on the balconies, there are some obstacles*** that severely limit the possibilities of intervention. The presence of railings, as well as the narrow spaces, make it difficult to intervene with prefabricated systems that would involve temporary removal of the railings themselves, the creation of temporary fall protection parapets, etc. If, on the other hand, we consider that balconies are in fact stable floors on which to intervene in complete safety, it is more natural to imagine that the most suitable intervention is by means of an external insulation system, both in terms of costs and ease of procedures.

This consideration, at the script level, translates into the need to eliminate these portions from the set of geometries on which we intend to operate. Having identified the perimeter of the terraces - and all the considerations seen above are valid - we went to make solid extrusions that identified parallelepipeds to be subtracted from the overall geometry.

Therefore, wanting to perform a subtraction of volumes and therefore having both the entire building and the balconies available, a solid trim operation was performed.

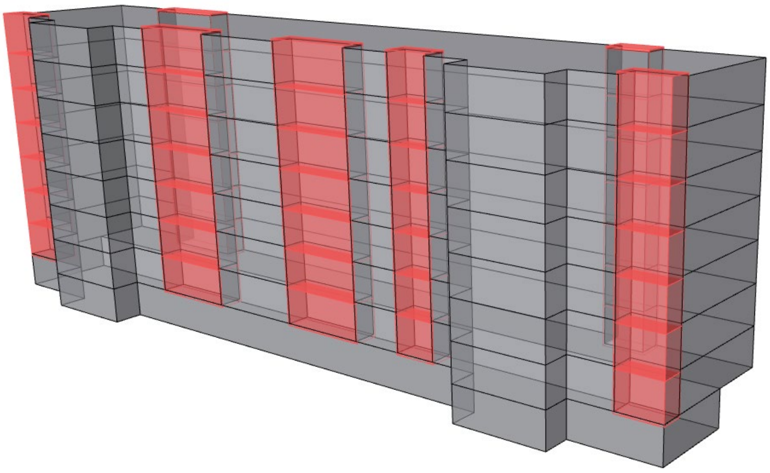


Figure 4.29_ Solid subtraction, Building - Balconies

It generated an open Brep which, once decomposed into its constituent faces, was used as the basis for the subsequent steps of the tool (note how the surfaces thus obtained still maintain the direction of the axes we set before).

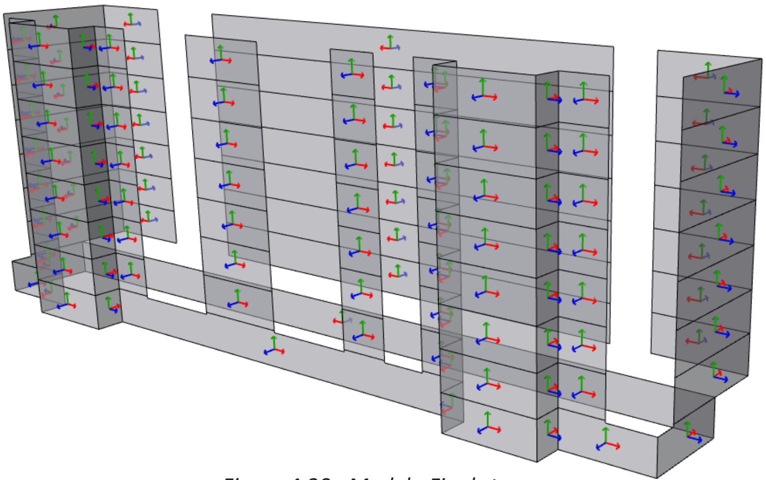


Figure 4.30_ Model - Final stage

The script gives the **possibility to choose whether to panel the surface of the balconies** or not.

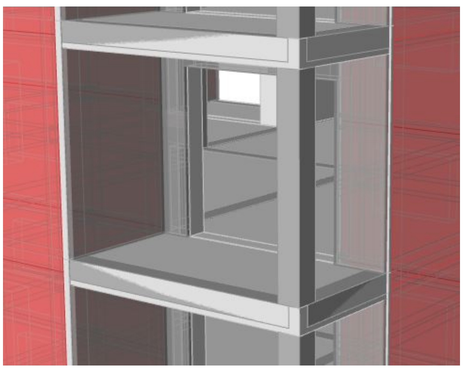


Figure 4.32_ Lodges NOT panelized.

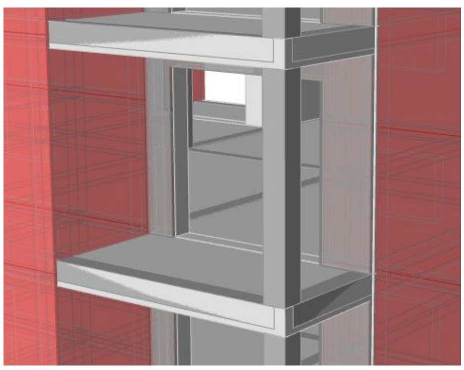


Figure 4.31_ Lodges panelized.

4.3 Adopted systems for the requalification

As we have said, prefabrication is slowly entering the world of energy redevelopment and now more than ever, we want to investigate solutions that can somehow represent the various cases currently on the market.

To give a more precise idea of the true extent of this phenomenon, it is reported a list (incomplete) of the main typology to date developed, differentiate for applicability on the residential type or not, the field of application (façade, roofing), dimensional flexibility, type of substructure, plant integrability, etc [68].

Progetto	Descrizione	Prefabbricazione				Applicazione								Dimensioni		Finitura		Integrazione Impiantistica					
MeeFs	Facciata modulare	✓			✓	✓						✓			✓	✓		✓					
More Connect	Pannelli prefabbricati per la riqualificazione energetica	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
New-TREND	Metodo di progettazione integrata di recupero								✓			✓	✓										
NeZer	nZeb + Renovation + RES								✓			✓						✓					
Opteemal	Piattaforma per il recupero a scala urbana	✓						✓	✓			✓	✓										
P2Endure	Riqualificazione con sistemi Plug-and-Play	✓						✓	✓					✓		✓	✓	✓	✓	✓			
RE4	Sviluppo pannelli prefabbricati da materiali riciclati	✓				✓		✓	✓	✓	✓	✓											
REFURB	Piattaforma di mercato tra costruttore e investitore								✓			✓	✓					✓	✓				
Rennovates	Metodo di recupero energetico degli edifici	✓				✓	✓		✓				✓					✓	✓				
RetroKit	Soluzioni prefabbricate per la riqualificazione	✓							✓									✓					
Sinfonia	Riqualificazione sistematica su scala urbana	✓		✓		✓		✓						✓		✓		✓	✓	✓			✓
smartTEST	Integrazione smart-grid	✓																✓	✓				✓
TES	Pannelli prefabbricati per la riqualificazione energetica	✓				✓		✓		✓	✓							✓	✓	✓			✓
Transition-Zero	Pannelli prefabbricati per riqualificare su ampia scala	✓		✓		✓			✓			✓	✓	✓		✓		✓	✓	✓		✓	✓
Veep	Pannello prefabbricato con materiali riciclati	✓								✓	✓												
Zebra2020	Monitoraggio del mercato delle costruzioni NZEB												✓										
4RinEU	Riqualificazione di edifici residenziali su ampia scala	✓		✓		✓						✓	✓	✓				✓					
A2Pbeer	Riqualificazione edifici pubblici										✓		✓										
Abracadabra	Metodo di mercato per edifici da riqualificare	✓										✓	✓										
Adaptiwall	Pannello prefabbricato leggero ad alta efficienza	✓				✓					✓			✓		✓					✓		
Bertim	Pannelli prefabbricati per la riqualificazione energetica	✓	✓	✓		✓		✓	✓					✓		✓			✓	✓	✓		
Bresaer	Facciata modulare standardizzata	✓		✓	✓	✓		✓	✓			✓			✓	✓	✓	✓					
BuildHeat	Recupero energetico edifici residenziali	✓										✓	✓	✓				✓	✓	✓			✓
CETIEB	Metodo di mercato per edifici da riqualificare											✓						✓					
E2ReBuild	Riqualificazioni per dimostrare la potenzialità di mercato	✓											✓					✓	✓		✓		✓
E2Vent	Modulo scambiatore di calore e energy storage	✓				✓									✓						✓		
EASEE	Pannello prefabbricato per il retrofitting	✓				✓		✓	✓	✓					✓								
Eensulate	Vetro innovativo per la riqualificazione degli edifici	✓									✓												
HERB	Riqualificazioni mediante soluzioni innovative	✓									✓							✓	✓				
IEA Annex 50	Pannelli prefabbricati in campo residenziale	✓		✓		✓	✓			✓		✓	✓	✓		✓		✓	✓				✓
Impress	Ottimizzazione del processo di pannelli prefabbricati	✓				✓			✓		✓												
Insiter	Ispezione in fase di lavoro e gestione per un recupero	✓						✓	✓			✓											
INSPiRe	Sistema di riqualifcazione verso edifici nZEB	✓											✓					✓					

Figure 4.33_Solutions currently on the market

The solutions chosen for the three types of redevelopment systems are therefore described below.

ETICS

ETICS (*External Thermal Insulation Composite Systems*) represent one of the main options for thermal insulation and external finishing of opaque closures [69]. they indicate an opaque facade wall system equipped with an external cladding consisting of insulating panels placed in place by glueing and/or mechanical fixing, covered with a thin reinforced skim coat, which is in turn finished on the surface with a thin layer of coloured coating paste that ensures adequate protection against bad weather.

Figure 4.34_ ETICS system - Rockwool

A continuous layer is thus created over the entire surface of the building, which allows reducing the energy needs of the building because of the improved **thermal performance** and reduced thermal bridges. In fact, it offers the possibility of easily placing the insulation layer on the external face of the infill masonry, thus neutralizing the effects of thermal bridges deriving from the geometric and material heterogeneity present.

The other advantages offered by this type of solution are therefore the "*limited*" disturbance to the occupants of the building, especially if we consider the entire work carried out externally by means of scaffolding and the possibility of architectural redevelopment of the building by modifying the external appearance (intrinsic value of the property, etc.).

Considerations can be made regarding the **hygrometric behaviour** and wet-dry surface cycles, which means the formation of surface/interstitial condensation and the possibility of disposing of the quantity of water in liquid form that remains on the external surface of the solution; these phenomena affect the conditions of hygiene and healthiness of the environments, as well as having an influence on the energy performance as well as on the durability and aesthetic appearance of the solutions themselves.

As far as the formation of condensation is concerned, we can refer to the specific legislation (*Decreto Ministeriale 26 Giugno 2015* "Requisiti Minimi", *UNI EN ISO 13788*, *UNI EN 15026*), separate reasoning must be made for the wet/dry cycles. With reference to the intrinsic properties of the external cladding system which tends to concentrate the thermal difference within the thickness of the insulation and therefore to present an external surface temperature close to that of the external air, we can run into the risk that the droplets of water do not evaporate and therefore preferential areas are created for the formation of mould, which spoils the aesthetic finish of the system itself.

With reference to **fire behaviour**, it is useful to underline how this system is not particularly affected by the fire problem - *if correctly designed*; in fact, it is sufficient that the infill wall has precise values of fire resistance (i.e. E60 (o→i), etc.) and its various components are non-combustible materials (insulation, fixing plugs, reinforced skim coat and finish). With specific reference to the insulating material, we must pay particular attention to the use of non-combustible materials to limit and slow down the spread of flames on the façade; for this reason, *Rockwool* panels of fire reaction class A1 have been used, that when subjected to fire, they do not release polluting and/or toxic substances into the environment.

Considering a classic construction method (i.e. with a reinforced concrete frame, brick-concrete floors and brick-block infill walls) and in order to ensure the mutual respect of behaviour between the different existing materials/redevelopment, extreme attention must be paid to the **installation** of the same as well as all the other indications provided by special manuals of qualified manufacturers and installers (to draw up these brief information sheets has been used the model developed by Rockwool in collaboration with the *ABC department of the Politecnico di Milano* and in particular *Prof. Eng. Angelo Lucchini, Enrico Sergio Mazzucchelli and Alberto Stefanazzi*).

To briefly report the main laying phases of an ETICS system, firstly we proceed with the laying of the layer of insulation by glueing and mechanically fixing every single panel (glue + fixings), after checking the planarity and cleaning of the support, laying out the laying surface, etc. Then we proceed with the layer of thin reinforced plaster on the panel, by applying two coats of smoothing and interposition between one coat and the other of an alkali-resistant fibreglass reinforcement mesh; the function that this layer has is to absorb the tensile stresses that stress the coating layer (temperature and relative humidity, etc.) and which could damage the levelling and insulating panel. Everything is then closed with the laying of the surface finishing layer and protection from external atmospheric agents.

Figure 4.35_ ETICS Manual - Rockwool

EASEE

The objectives set by the EASEE research (*Envelope Approach to improve Sustainability and Energy Efficiency in Existing multi-storey, multi-owner residential buildings*) are to provide new **modular solutions** for the envelopes of multi-storey residential buildings, **combining thermal insulation and external surface finishing** in a single large panel [35 9 12 54].

These new technologies developed, with supporting processes and software, will be part of a new **holistic approach** that aims to reduce the time and costs associated with this activity while ensuring better energy performance, construction process and simplified installation procedures (no scaffolding, etc.), visual quality, reduced discomfort for the occupants, etc.

Although the research studies have focused on solutions inside / in the cavity / outside the perimeter wall and in this case both monolayer and multilayer solutions have been proposed, we will focus our analyzes only on this last solution. This is an innovative **composite panel** is made of Textile Reinforced Mortar (TRM) (int.) + Insulation layer (EPS) + Textile Reinforced Mortar (TRM) (ext.).

The **tests conducted** on the materials concerned both the structural aspects (bending on four points, residual mechanical properties after freeze-thaw cycles, dimensional stability, etc.), as well as the hygrothermal behaviour, LCA, anchoring and installation and aesthetic appearance.

TRM is a cementitious composite reinforced with a structure in glass, carbon or aramid fibres and is in fact the load-bearing layer of the panel, with the layer of insulation acting as load transfer. The choice of the insulating material is mainly due to its low cost and its hygrothermal and mechanical properties, together with the possibility of being cut to the desired size; specifically, considering its mechanical properties, it is optimal for its not excessive stiffness, good compression/traction properties and good shear modulus value.

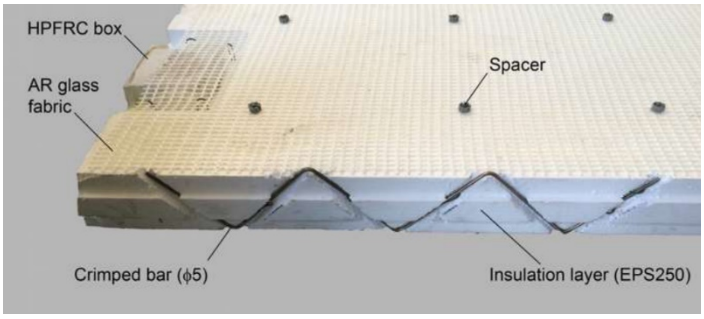


Figure 4.36_ Panel layers. Credits: EASEE_ Envelope Approach to improve Sustainability and Energy Efficiency in multi-storey multi-owner residential buildings

During the design phases of the panels, it was essential to study the critical points of the facade, such as the panel-panel joints and the interfaces with windows and balconies; the studio had to meet the requirements of the possibility of replacing damaged panels on the façade, airtightness, assembly tolerances and freedom of relative movements with the elements that make up the façade.

The **joint solutions** were solved by combining two products: a sealing polyethylene backer coupled with an acrylic silicone sealant with a low modulus of elasticity. The infill bead (diameter 20 mm), non-absorbent and non-degradable, allowed the filling of the joints before the application of the silicone material, while the silicone sealant with low modulus (resistant to ageing and with a wide range of application temperatures) allowed the perfect sealing of joints and connections between panels, a solution that also allows accommodating all movements avoiding fractures and detachments. This solution has good thermal properties and the thermal flux, despite having peaked at the joint, is almost parallel to the isotherms on the outer layer, demonstrating how the heat transferred is substantially 1D (no thermal bridge).

Figure 4.37_ Sealing joint

The **procedure for installing** the panels first involves the positioning of the metal support elements, corresponding to the lower part of the panel, then follows the lifting of the panel by means of a hook hung from a crane and their positioning. Subsequently, for each panel and by means of a mobile lifting platform, we proceed with the laying of the polyethylene cord and silicone sealant to ensure air, water and weather tightness. It is therefore evident that all operations are carried out in conditions of absolute safety and cleanliness of the site.

In any case, during the construction phase, some details have been improved to have better and faster solutions in the connections between the EASEE solution and the traditional solutions and finishing solutions near balconies and windows.

Figure 4.38_ Installation process

TES Energy Façade

TES Energy Façade is the result of European research based on the definition of a renovation process of the facades of buildings/energy retrofit with **prefabricated wooden panels** [30 36]. The strength of the project lies in the versatility of the product, the arrangement of all the components of the facade system (windows, casings, ...) in a single system, the versatility of adaptation to different types of buildings (residential, commercial, industrial, ...), the speed of assembly, monitored management of the different processes (from production to installation) also through the use of BIM platforms and the possibility of modifying the different surface finishes according to the users' needs.

Figure 4.39_ Wood trunks

Although the use of **wood in the construction sector** has increased, the practice of renovations in Italy does not consider the potential of prefabricated lightweight systems. Rediscovered in the last ten years, this material has been the subject of specific studies on its ecological potential as a building material. As a result of the research conducted by CORRIM (Consortium of research on renewable Industrial Materials) on the environmental potential of various building materials, wood is the one with the highest potential.

In fact, its strength depends on its biological origin and as a renewable resource, it retains a large amount of carbon inside it, which guarantees a surplus for the following processes: the transformation phase, in turn, consumes a low amount of energy, thus leading the material to have a low amount of residual embodied energy. Furthermore, the possibility of completely dry construction ensures easy disposal and recyclability at the end of its primary use, which extends the overall life cycle of wood products.

The development of **Information Technology** and the use of the first **Numerical Control Machines** (CNC) has certainly pushed the use of this material while ensuring both industrial standardization and customization based on needs. Furthermore, the continuous optimization of the production process has allowed the reduction of waste and production time, allowing to save money and resources. The level of prefabrication offered is however well defined by the type of technology used, by the dimensions of the component to be produced and by the transport and installation limits, allowing to reach high-quality levels.

Figure 4.40_ TES Solution

With specific reference to the **wooden substructure** of the panel, the advantages in this type of approach are the easy workability and customization, low weight (compared to steel, ...) and the possibility of having various shapes; the disadvantages, on the other hand, are that compared to other construction materials it has the lower bearing capacity and the problem of combustion.

As for the system implementation phases, first of all, an EPDM sheath is placed in correspondence with the perimeter beams of the building with a thermal break function, on which a wooden element is placed that will act as a support for the entire prefabricated panel. This is in fact made up of a structural wooden grid (mullions and transoms) and the attachment to the substructure takes place precisely on these horizontal elements placed at the ends of the panel by means of long wood screws, which determine the flatness of the surfaces; The interface between two vertically and horizontally contiguous panels is made using wedges. The gap between the old wall and the new one (about 5.0 cm) can be filled with insulating material or left as an air cavity of "*still air*".

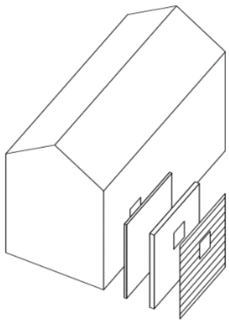


Figure 4.41_ Possible TES configuration: existing structure (a), adaptation layer (b), timber framework and insulation as main layer (c), cladding layer on the exterior side (d)

The work on site is necessary for the connections between the panel and specific elements such as balconies and windows, which require greater technical efforts than the rest; the interface between the base module and the frame must in fact be carefully developed with reference to air tightness and thermal bridges.

Referring to the analysis for fire prevention, to avoid the spread of fire through the air gap, it is necessary to fill the cavity with suitable material or to place a horizontal barrier at the height of each intermediate floor.

4.4 Reference Excel file

CHAPTER'S SUMMARY:

This chapter introduces the contents of the sheets in the Excel reference file, a document offered with our tool to let everyone to view the results of the various analysis of our case study. However, its importance goes far beyond, allowing us to interact with the parametric modelling software in data input/output. This bridge actually forms the basis for future implementations, as it is sufficient for the new data to appear here to be integrated into the tool.

The reference Excel file is one of the documents supplied with our tool. This is of fundamental importance as it exchanges important information in real-time with the Grasshopper file. The initial inputs that initiate the analysis are contained in this document, furthermore, the outputs of the results obtained from the analysis in Grasshopper are then exported to this document, making the data accessible to anyone.

The Excel document consists of **several sheets dedicated to different topics**, which are briefly described in this chapter. The information contained within them will be shown in subsequent chapters as our methodology is explained.

In this first version of our tool, the sheets in the reference Excel file are 16:

1. **Constraints_TES:** in this sheet of the Excel file, it is possible to choose the dimensional limits of the TES panels that will redevelop the facade of our case study.

2. **Constraints_EASEE:** in this sheet of the Excel file, it is possible to choose the dimensional limits of the EASEE panels that will redevelop the facade of our case study.

3. **Layers:** this sheet of the Excel file, is dedicated to containing the layers of all the technologies present in our analysis, both the original layers of our case study and the new configurations hypothesized by us. After inserting in special tables containing formulas, the following values for each layer:
    - *Thickness (mm)*
    - *Thermal conductivity λ [W/m*K]*
    - *Gross density [kg/m^3]*
    - *Specific heat capacity C [J/Kg*K]*
    - *Coefficient of resistance to water vapour diffusion [-]*

   It's possible to have interesting data as an output, such as:

    - *Weight [Kg/m^2]*
    - *Heat transfer coefficient [W/m^2*K]*
    - *Thermal resistance [m^2*K/W]*
    - *Resistance to vapor permeation [Pa*s*m^2/Kg]*

N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m²]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m²/kg]	
1						0.00	0.00	0.00		0.00E+00	0.00E+00	INTERNAL
2						0.00	0.00	0.00		0.00E+00	0.00E+00	
3						0.00	0.00	0.00		0.00E+00	0.00E+00	
4						0.00	0.00	0.00		0.00E+00	0.00E+00	
5						0.00	0.00	0.00		0.00E+00	0.00E+00	EXTERNAL

Legend:	
	Value to insert

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m²]	U_{TOT} [W/m²*K]	R_{TOT} [m²*K/W]	Z_{TOT} [Pa*s*m²/kg]
0	0.00	0.00	0.00	0.00E+00

Figure 4.42_ Layer's properties layout in sheet 3 "Layers".

4. **Weight_U-value comparison:** this Excel sheet is dedicated to comparative analysis related to the properties of the configurations, as their thickness varies (for example by varying the thickness of the insulating layer).

5. **Layer's properties comparison:** in this Excel sheet, the following parameters of the various configurations are compared with grouped columns.
   - *U-value [W/m2K]*
   - *Decrement factor f [-]*
   - *Internal areal heat capacity [kJ/m2K]*
   - *Periodic thermal transmittance [W/m2K]*
   - *Time shift periodic thermal transmittance [h]*

6. **Therm_Hygrometric:** in this Excel sheet an in-depth study of the hygrometric behaviour of the analyzed configurations is carried out. The results can be viewed analytically and with the Glazer diagram.

7. **Wind-load:** this Excel sheet carries out the calculations necessary to obtain the wind load acting on our facade, which is important for structural analysis.

8. **Building:** this Excel sheet contains data regarding the geometry of the building, and the value of H't (global average heat exchange coefficient) is calculated, which is important for the energy analysis of the building (see Chapter "*Energy 2.0*").

	TES ENERGY FAÇADE	Area [m²]	EASEE	Area [m²]	ETICS	Area [m²]
H_D [W/K]		0.00				
H_g [W/K]		0.00				
H'_T [W/m²K]	**0.00**	**[W/m²K]**	**0.00**	**[W/m²K]**	**0.00**	**[W/m²K]**
	0.00	[W/K]	0.00	[W/K]	0.00	[W/K]
	OK		OK		OK	

→

TES ENERGY FAÇADE	EASEE	ETICS	
Upper Limit	Upper Limit	Upper Limit	
0.00	0.00	0.00	[W/m²K]
0.00	0.00	0.00	[W/K]
IMPORTANT REQUALIFICATION I° LEVEL	IMPORTANT REQUALIFICATION I° LEVEL	IMPORTANT REQUALIFICATION I° LEVEL	

Figure 4.43_ Layout of the sheet 8 "Building".

9. **Ψ:** this Excel sheet calculates the dispersions due to linear thermal bridges, which are important for the evaluation of building dispersions. These values are inserted in the Grasshopper file for the calculation of H_D (direct heat exchange coefficient for transmission to the external environment).

10. **H_D:** in this Excel sheet, Grasshopper inserts the data necessary for the calculation of H_D (direct heat exchange coefficient for transmission to the external environment), an important parameter for the calculation of H't (in the "8_Building" sheet).

11. **H_g:** this Excel sheet shows the data necessary for the calculation of H_g (the stationary heat exchange coefficient for transmission to the ground), another parameter necessary for the calculation of H't (in the "8_Building" sheet).

12. **ETICS_BOQ:** in this Excel sheet an estimate is made of the time and costs necessary for the realization of the ETICS system, only on the surface where the EASEE and TES prefabricated solutions are applied.

13. **EASEE_BOQ:** in this Excel sheet an estimate of the times and costs necessary for the requalification of the facade with EASEE panels is made. Surfaces that are subject to redevelopment with other solutions (for example, the roof) are excluded. This is because our study wants to have a focus on the differences between traditional systems or systems with prefabricated panels and moreover, the solutions adopted in the other areas are the same for the 3 systems analysed (ETICS, EASEE and TES), therefore they do not affect our analysis.

14. **TES_BOQ:** in this Excel sheet an estimate of the times and costs necessary for the reconstruction of the facade with TES panels is made. In this sheet, the same reasoning made for sheet "13_EASEE_BOQ" applies.

15. **Comparison_BOQ:** this Excel sheet compares the results of the three sheets described above (sheets 12, 13 and 14). Thanks to Excel graphs, it is possible to view the influence of the cost of materials, the operating team and rentals on the total obtained.

16. **Windows:** in this Excel sheet it is possible to make an in-depth study on transparent surfaces, in order to be able to calculate their thermal transmittance.

4.5 Analysis

Energy 1.0

CHAPTER'S SUMMARY:

The purpose of this chapter is to begin the energy analysis by evaluating the thermal transmittance (U-value) of opaque walls and the relative hygrometric behaviour: this allows us to have a first parameter to evaluate whether the type of intervention we want to carry out on our façade respects the regulatory limits.

Goals

To determine the checks to be respected, we followed the indications provided by the **current Regulations** (Directive 2002/91/EC, Directive 2010/31/EU and National applications: Legislative Decree 192/05 and subsequent amendments, Legislative Decree 63/13 converted by Law 90/2013 and the Ministerial Decree of 26 June 2015). In particular, the design ideas provided by the "mini ANIT GUIDE" [70], which proposes the **list of checks to be followed** - and the requirements of each - on the basis of:

- **"Scope of application"** (*Ministerial Decree 26/6/15*);
- **"Classification of the building"** (*Presidential Decree 412/93*).

As regards the Areas of Application, it was decided to adopt an **important I° level Restructuring** (*Annex 1 Art. 1.4.1*) which includes at the same time:

- an **intervention** that affects the **building envelope** with an incidence **> 50%** of the total gross dispersing surface of the building, where the dispersing surface means "the gross dispersing surface of the opaque and transparent elements that delimit the volume at a controlled temperature by the external environment and non-air-conditioned environments" (*FAQ 2.13 Aug 2016*);
- the **restructuring of the heating system** for the winter and/or summer air conditioning service serving the entire building, where the restructuring of the system means "the set of works that involve the substantial modification of both the production and distribution systems and heat emission "(*Legislative Decree 192/2005 All. A*).

As regards the **Classification of the Building**, on the other hand, reference was made to Buildings used as **residences** and similar (**E.1**).

Therefore, by crossing the Scope of application with the Classification of the building, the list of requirements to be respected is obtained (DM 26/6/15):

			Imp. + S > 50%	S > 25%	S ≤ 25%		
E1(1) E1(2) E1(3) E2 E3 E4 E5 E7	A,B,D,F,G, H,J,K,L*,M, P,Q,R,S, T,W,X,Y	B,F,H, K,Q,S, T,W,Y	A,B,D,E,F,G, H,J,K,L*,M, P,Q R,S, T,W,X,Y	B,C,E,F,I, K, L*	C,E,F,I, K,Q	E, M,N, Q, R,S, U,V, W,X,Y	M,O, Q, R,S, W,X
E6	A,B,D,F, H,J,K,L*,M, P,Q R,S, T,W,X,Y		A,B,D,E,F, H,J,K,L*,M, P,Q R,S, T,W,X,Y				
E8	A,B,F, H,J,K,L*,M, P,Q R,S, T,W,X,Y		A,B,E,F, H,J,K,L*,M, P,Q R,S, T,W,X,Y	B,C,E,F, K, L*	C,E,F, K,Q		

A	Verificare che $EP_{H,nd}$, $EP_{C,nd}$ e $EP_{gl,tot}$ siano inferiori ai valori limite *(All. 1 Art. 3.3 comma 2b.iii e comma 3, App.A)*
B	Verificare che H'_T sia inferiore al valore limite *(All.1 Art. 3.3 comma 2b.i e Art. 4.2 comma 1b, App.A)*
C	Verificare che la trasmittanza delle strutture opache e chiusure tecniche rispetti i valori limite *(All.1 Art. 5.2, comma 1a,b,c, Art. 4.2, comma 1a, Art. 1.4.3 comma 2, App. B)*
D	Verificare che la trasmittanza dei divisori sia inferiore o uguale a 0.8 W/m^2K *(All.1 Art.3.3 comma 5)*
E	Le altezze minime dei locali di abitazione [...] possono essere derogate fino a 10 cm. *(All.1 Art.2.3 comma 4)*
F	Verificare l'assenza di rischio di formazione di muffe e di condensazioni interstiziali. *(All. 1 Art. 2.3 comma 2)*
G	Verificare nelle località in cui $I_{m,s} \geq 290$ W/m^2, che le pareti opache verticali, orizzontali e inclinate rispettino i limiti di trasmittanza periodica (Y_{IE}) e massa superficiale (M_s) *(All.1 Art. 3.3 comma 4b,c)*
H	Verificare che il rapporto $A_{sol,est}/A_{sup\ utile}$ rispetti i limiti previsti *(All.1 Art. 3.3 comma 2b.ii,App.A)*
I	Verificare che per le chiusure tecniche trasparenti $g_{gl+sh} \leq 0{,}35$ *(All.1 Art. 5.2 comma 1d e Art. 4.2 comma 1a)*
J	Valutare l'efficacia dei sistemi schermanti delle superfici vetrate *(All.1 Art.3.3 comma 4a)*
K	Verificare l'efficacia, per le strutture di copertura, dell'utilizzo di materiali a elevata riflettanza solare e di tecnologie di climatizzazione passiva *(All.1 Art 2.3 comma 3)*
L	Rispettare gli obblighi di integrazione delle fonti rinnovabili termiche ed elettriche secondo quanto previsto dal DLgs 28/11 e s.m. *(All.1 Art. 3.3 comma 6, All.3 DLgs28/11)*
M	Verificare che i rendimenti η_H,η_W e η_C siano maggiori dei rispettivi valori limite *(All.1 Art. 3.3 comma 2b.iv, Art. 5.3.1 comma 1a, Art 5.3.2 comma 1a, Art. 5.3.3 comma 1, App.A)*
N	Realizzare una diagnosi energetica dell'edificio e dell'impianto *(All.1 Art. 5.3 comma 1)*
O	Rispettare i limiti e le regole previste per la sostituzione generatore di calore, la sostituzione di macchine frigorifere e la sostituzione di generatori di calore per l'ACS *(All. 1 Art. 5.3.1 comma 1d, Art. 5.3.2 comma 1c, Art. 5.3.3 comma 1, App.B)*
P	Per gli edifici ad uso non residenziale, è obbligatorio un livello minimo di automazione le tecnologie dell'edificio e degli impianti termici *(All 1. Art. 3.2 comma 10)*
Q	Rispettare i limiti e le regole per la termoregolazione *(All 1. Art. 3.2 comma 7 , Art. 5.2 comma 2, Art. 5.3.1 comma 1b, Art. 5.3.2 comma 1b)*
R	Rispettare i limiti e le regole per la contabilizzazione del calore. *(All 1. Art. 3.2 commi 8,9, Art. 5.3.1 comma 1c, Art. 5.3.2 comma 1b*
S	Rispettare i limiti e le regole per l'installazione di generatori di calore a biomasse *(All. 1 Art. 2.3 comma 4)*
T	In caso di presenza di reti di teleriscaldamento e teleraffrescamento in prossimità dell'edificio in progetto è obbligatorio predisporre i collegamenti *(All. 1 Art. 3.2 commi da 1 a 6)*
U	Rispettare i limiti e le regole per la sostituzione di apparecchi di illuminazione *(All. 1 Art. 5.3.4 comma 1)*
V	Rispettare i limiti e le regole per l'installazione, sostituzione o riqualificazione degli impianti di ventilazione *(All. 1 Art. 5.3.5 comma 1)*
W	Rispettare i limiti e le regole per il trattamento dell'acqua di impianto e la contabilizzazione del volume di acqua calda sanitaria *(All.1 Art. 2.3 commi 5 e 6)*
X	Rispettare i limiti e le regole per la micro cogenerazione *(All.1 Art. 2.3 comma 7)*
Y	Rispettare i limiti e le regole per ascensori e scale mobili *(All.1 Art. 2.3 comma 8)*

Table 4.1_ Scheme of possible checks to be performed.

Specifically, we, therefore, went back to the study of:

B	Verificare che H'_T sia inferiore al valore limite *(All.1 Art. 3.3 comma 2b.i e Art. 4.2 comma 1b, App.A)*
D	Verificare che la trasmittanza dei divisori sia inferiore o uguale a 0.8 W/m^2K *(All.1 Art.3.3 comma 5)*

underlining that at the regulatory level the verification of the transmittance of opaque structures is not required as per *Annex 1 Art. 5.2*, paragraph 1a, b, c, *Art. 4.2*, paragraph 1a, *Art. 1.4.3* paragraph 2, *App. B* (*DM 26/6/15*).

Layers and Thermal Transmittance

One of the main reasons why it is decided to renovate the facade of a residential building from the 70s/80s is due to energy consumption problems, due to the fact that the performance of the building envelope decreases over time and that the materials used once they cannot have the performances of the materials used today.

That is why, we studied the possible configurations with which we can work on the facade, analyzing two very **important parameters for the energy performance of the building**:

- **The thermal transmittance of the wall;**
- **The hygrometric behaviour of the wall.**

In order to evaluate the thermal transmittance of the opaque envelope, the calculations have been referred to the UNI EN ISO 6946:2008 about "Elements and components of buildings, Thermal Resistance and Transmittance, methods of calculations" and UNI EN ISO 13786 method of calculations.

Thermal Transmittance is defined as: "A heat flow running through a unitary surface subjected to a temperature difference equal to 1°C and it's linked to the material features that constitute the structure and to the heat exchange liminal conditions" and it's also the inverse of the sum of the layer's thermal resistances:

$$U = \frac{1}{R_{total}} \quad \left[\frac{W}{m^2K}\right]$$

with: $R_{total} = R_{SI} + R_1 + R_2 + \cdots + R_N + R_{SE}$

In which:

• R_{SI} = Interior Surface Thermal Resistance (according to the norm by climatic zone)

• R_{SE} = Exterior Surface Thermal Resistance (according to the norm by climatic zone)

• R_1, R_2, ... R_N = Thermal Resistances of each layer, which is obtained according to:

$$R = \frac{d}{\lambda} \quad \left[\frac{m^2K}{W}\right]$$

In which:

d = Total thickness of the layer (m)

λ = Useful thermal conductivity calculated according to ISO/DIS 10456.2 or taken from given tabulated values.

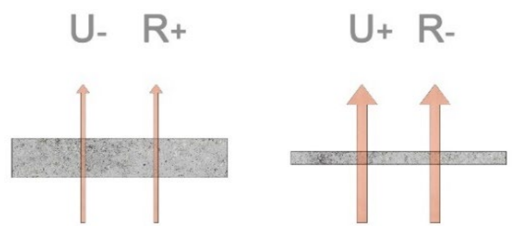


Figure 4.44_ U-value and Thermal Resistance. Credits: Archdaily

Particular attention was paid to the calculation of the **thermal resistance for ventilated air cavity** (see all the layers on the following pages); for this consideration, the UNI EN ISO 6946:2008 was still considered.

The thermal resistance values of the cavities differ depending on whether this is evaluated:

- Non-ventilated air cavity;
- Lightly ventilated air cavity;
- Strongly ventilated air cavity.

And depending on the direction of the heat flow (Upward, Horizontal or Downward).

Specifically, the **EASEE configuration** has an **air cavity** that was considered **unventilated** as it meets the following conditions:

- the openings are arranged so as not to allow a flow of air through the interspace;
- the openings are not greater than 500 mm^2 per meter in length for vertical air gaps;
- the openings are not greater than 500 mm^2 per square meter of surface (wall) for horizontal air spaces.

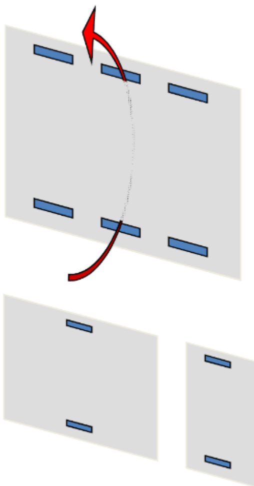


Figure 4.45_Scheme non-ventilated air cavity

The thermal resistance values adopted are provided by the following table:

	Non-ventilated air cavity		
Air cavity thickness [mm]	Heat flux direction		
	Upward R [m^2K/W]	Horizontal R [m^2K/W]	Downward R [m^2K/W]
0	0.00	0.00	0.00
5	0.11	0.11	0.11
7	0.13	0.13	0.13
10	0.15	0.15	0.15
15	0.16	0.17	0.17
25	0.16	0.18	0.19
50	0.16	0.18	0.21
100	0.16	0.18	0.22
300	0.16	0.18	0.23

Table 4.2_ Thermal resistances for non-ventilated air cavity.

The **TES configuration**, on the other hand, has a ventilated façade that has been considered a **strongly ventilated cavity** as it meets the following condition:

- more than 1500 mm^2 per meter of length for vertical air spaces.

In this case, the thermal resistance of the air gap and of all the layers that separate it from the external environment is neglected and including an external surface thermal resistance corresponding to the still air (R_{SI}).

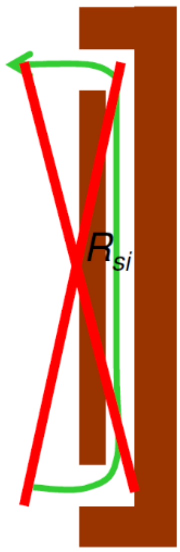


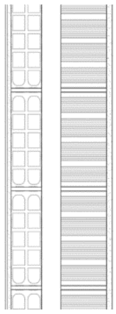
Figure 4.46_ Scheme strongly ventilated air cavity.

The boundary conditions that we defined are the following:

Boundaries Conditions			
T_{INT} [°C]	20.00	UR_i [%]	50
T_{EST} [°C]	-5.00	UR_e [%]	85
h_i [W/m^2*K]	8	R_i [m^2*K/W]	0.13
h_e [W/m^2*K]	25	R_e [m^2*K/W]	0.04

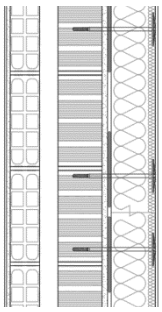
Figure 4.47_ Boundaries conditions.

We show below the layers of the studied configurations and the corresponding properties, starting from the base case on which we carried out the redevelopment.



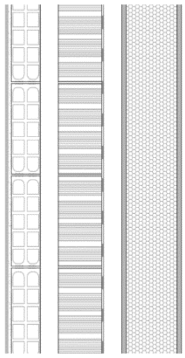
CV01 - BASE CASE												
N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m^2]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m^2/kg]	
1	Internal Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	INTERNAL
2	Hollow Blocks	80	0.20	600.00	1000.00	48.00	2.50	0.40	16.00	1.25E-11	6.40E+09	
3	Air Cavity	50	0.18	1.30	1000.00	0.07	3.60	0.28	1.00	2.00E-10	2.50E+08	
4	Hollow Bricks	120	0.24	600.00	1000.00	72.00	2.03	0.49	16.00	1.25E-11	9.60E+09	
5	External Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	EXTERNAL

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m^2]	U_{TOT} [W/m^2*K]	R_{TOT} [m^2*K/W]	Z_{TOT} [Pa*s*m^2/kg]
290	196.07	0.72	1.39	2.01E+10



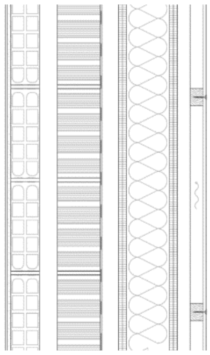
CV02 - BASE CASE + INSULATION												
N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m^2]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m^2/kg]	
1	Internal Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	INTERNAL
2	Hollow Blocks	80	0.20	600.00	1000.00	48.00	2.50	0.40	16.00	1.25E-11	6.40E+09	
3	Air Cavity	50	0.18	1.30	1000.00	0.07	3.60	0.28	1.00	2.00E-10	2.50E+08	
4	Hollow Bricks	120	0.24	600.00	1000.00	72.00	2.03	0.49	16.00	1.25E-11	9.60E+09	
5	Lightweight Mortar	15	0.18	770.00	1550.00	11.55	12.00	0.08	12.00	1.67E-11	9.00E+08	
6	Insulation Frontrock Max E	120	0.04	90.00	1030.00	10.80	0.30	3.33	1.00	2.00E-10	6.00E+08	
7	External Finishing	6.5	0.55	1530.00	1550.00	9.95	84.62	0.01	12.00	1.67E-11	3.90E+08	EXTERNAL

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m^2]	U_{TOT} [W/m^2*K]	R_{TOT} [m^2*K/W]	Z_{TOT} [Pa*s*m^2/kg]
411.5	190.36	0.21	4.79	2.00E+10



N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m²]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m²/kg]	
	CV06 - EASEE Panel											
1	Internal Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	INTERNAL
2	Hollow Blocks	80	0.20	600.00	1000.00	48.00	2.50	0.40	16.00	1.25E-11	6.40E+09	
3	Air Cavity	50	0.18	1.30	1000.00	0.07	3.60	0.28	1.00	2.00E-10	2.50E+08	
4	Hollow Bricks	120	0.24	600.00	1000.00	72.00	2.03	0.49	16.00	1.25E-11	9.60E+09	
6	Vapour Barrier (DS 1500 SYN)	0.45	0.22	289.00	1700.00	0.13	488.89	0.00	6666667.00	3.00E-17	1.50E+13	
7	Spacer + Air cavity	50	0.28	1.30	1000.00	0.07	5.54	0.18	1.00	2.00E-10	2.50E+08	
8	TRC-Textile Reinforced Concrete	12.5	2.00	2311.00	1000.00	28.89	160.00	0.01	15000.00	1.33E-14	9.38E+11	
9	Insulation EPS	140	0.04	15.00	1450.00	2.10	0.26	3.78	30.00	6.67E-12	2.10E+10	
10	TRC-Textile Reinforced Concrete	12.5	2.00	2311.00	1000.00	28.89	160.00	0.01	15000.00	1.33E-14	9.38E+11	EXTERNAL

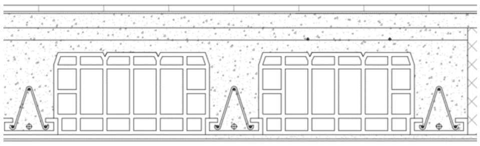
$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m²]	U_{TOT} [W/m²*K]	R_{TOT} [m²*K/W]	Z_{TOT} [Pa*s*m²/kg]
485.45	218.14	0.19	5.34	1.69E+13



N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m²]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m²/kg]	
	CV04 - TES WOOD PANEL											
1	Internal Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	INTERNAL
2	Hollow Blocks	80	0.20	600.00	1000.00	48.00	2.50	0.40	16.00	1.25E-11	6.40E+09	
3	Air Cavity	50	0.18	1.30	1000.00	0.07	3.60	0.28	1.00	2.00E-10	2.50E+08	
4	Hollow Bricks	120	0.24	600.00	1000.00	72.00	2.03	0.49	16.00	1.25E-11	9.60E+09	
5	Vapour Retarder (DB 135)	0.3	0.22	467.00	1700.00	0.14	733.33	0.001	66667.00	3.00E-15	1.00E+11	
6	Spacer + Air cavity	50	0.28	1.23	1000.00	0.06	5.54	0.18	1.00	2.00E-10	2.50E+08	
7	OSB Wood Panel	22	0.13	620.00	1600.00	13.64	5.91	0.17	150.00	1.33E-12	1.65E+10	
8	Stone Wool Insulation Panel (Fixrock 35 VF)	120	0.04	50.00	1030.00	6.00	0.29	3.43	1.00	2.00E-10	6.00E+08	
9	OSB Wood Panel	22	0.13	620.00	1600.00	13.64	5.91	0.17	150.00	1.33E-12	1.65E+10	
10	Air Cavity (strongly vent.) + Counter Battens 48x36 mm	72	0.28	1.23	1000.00	0.09	0.00	-	1.00	0.00E+00	-	
11	RockPanel Wood Cladding	8	0.35	1050.00	1600.00	8.40	0.00	-	110.00	0.00E+00	-	EXTERNAL

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m²]	U_{TOT} [W/m²*K]	R_{TOT} [m²*K/W]	Z_{TOT} [Pa*s*m²/kg]
564.3	200.03	0.19	5.40	1.52E+11

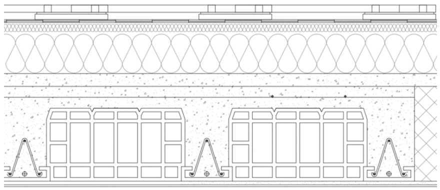
We report below the study of other important layers for future detailed energy analysis.



					CO01 - ROOF BASE CASE							
N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m²]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m²/kg]	
1	Internal Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	INTERNAL
2	Concrete - Brick slab (20+6)	260	0.75	1150.00	1000.00	299.00	2.88	0.35	15.00	1.33E-11	1.95E+10	
3	Screed	35	0.47	1200.00	880.00	42.00	13.43	0.07	35.00	5.71E-12	6.13E+09	
4	Roof tiles	20	0.55	1800.00	1000.00	36.00	27.50	0.04	10.00	2.00E-11	1.00E+09	EXTERNAL

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m²]	U_{TOT} [W/m²*K]	R_{TOT} [m²*K/W]	Z_{TOT} [Pa*s*m²/kg]
335	415.00	1.54	0.65	2.85E+10

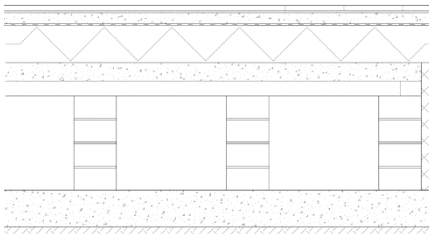
As you can clearly see in the tables above, the original roof ("*CO01-ROOF BASE CASE*") disperses a lot of heat and contributes to causing a situation of discomfort throughout the building (especially for those who live on the top floor). For this reason, we deemed it necessary to carry out a more in-depth study on the **roof**, which **will also be subject to redevelopment** (not with prefabricated panels). The intervention of requalification would result in the following configuration.



					CO03 - ROOF BASE CASE + INSULATION							
N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m²]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m²/kg]	
1	Internal Plaster	20	0.80	1900.00	1550.00	38.00	40.00	0.03	19.00	1.05E-11	1.90E+09	INTERNAL
2	Concrete - Brick slab (20+6)	260	0.75	1150.00	1000.00	299.00	2.88	0.35	15.00	1.33E-11	1.95E+10	
3	Screed	35	0.47	1200.00	880.00	42.00	13.43	0.07	35.00	5.71E-12	6.13E+09	
4	Insulation Flatrock 50	140	0.04	140.00	1030.00	19.60	0.26	3.89	1.00	2.00E-10	7.00E+08	
5	Waterproof membrane Protector SILVER 230	0.7	0.22	329.00	1700.00	0.23	314.29	0.003	143.00	1.40E-12	5.01E+08	
6	Roof tiles	20	0.55	1800.00	1000.00	36.00	27.50	0.04	10.00	2.00E-11	1.00E+09	EXTERNAL

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m²]	U_{TOT} [W/m²*K]	R_{TOT} [m²*K/W]	Z_{TOT} [Pa*s*m²/kg]
475.7	434.83	0.22	4.54	2.97E+10

No intervention was planned on the basement.



					CO02 - BASEMENT BASE CASE							
N°.	Layer	Thickness [mm]	Thermal conductivity λ [W/m*K]	Gross density ρ [kg/m³]	Spec. heat capacity C [J/kg*K]	Weight [kg/m²]	Heat Transfer Coefficient U [W/m²*K]	Thermal resistance R [m²*K/W]	μ [-]	δ_P [kg/Pa*s*m]	Z [Pa*s*m²/kg]	
1	Porcelain tail	10	1.00	2300.00	1000.00	23.00	100.00	0.01	40.00	5.00E-12	2.00E+09	INTERNAL
2	Screed layer	35	1.40	2100.00	1000.00	73.50	40.00	0.03	10.00	2.00E-11	1.75E+09	
3	Vapour Retarder (DB 150)	0.55	0.22	273.00	1700.00	0.15	400.00	0.00	9091.00	2.20E-14	2.50E+10	
4	Expanded Polystyrene	100	0.04	25.00	1400.00	2.50	0.42	2.381	40.00	5.00E-12	2.00E+10	
5	Concrete	50	0.47	1200.00	880.00	60.00	9.40	0.11	35.00	5.71E-12	8.75E+09	
6	Hollow brick	40	0.34	35.00	800.00	1.40	8.50	0.12	16.00	1.25E-11	3.20E+09	
7	Ventilated air cavity (strongly vent.)	255	0.50	1.23	1000.00	0.31	0.00	-	1.00	0.00E+00	-	
8	Concrete	100	0.98	1600.00	1080.00	160.00	0.00	-	25.00	0.00E+00	-	EXTERNAL

$Thickness_{TOT}$ [mm]	$Weight_{TOT}$ [kg/m²]	U_{TOT} [W/m²*K]	R_{TOT} [m²*K/W]	Z_{TOT} [Pa*s*m²/kg]
590.55	320.86	0.35	2.89	6.07E+10

WINDOWS THERMAL TRANSMITTANCE

Transparent surfaces (windows and French doors) were not the specific subject of our study. However, they are of fundamental importance for the energy analysis of the building, considering that they are the elements that disperse the most in a building. For this reason, in the sheet "*16_Windows*" of the reference Excel document, we have calculated the thermal transmittance value of the window that will be used for all the glazed surfaces in our case study (including French doors).

In order to calculate the thermal transmittance of the window it was necessary to analyse the transmittance of the glass and the frame and combine them according to EN ISO 10077:

$$U_W = \frac{\sum A_g U_g + \sum A_f U_f + \sum l_g \psi_g}{A_f + A_g}$$

Where:

- U_W: thermal transmittance of the window [W/m^{2}K]
- U_g: thermal transmittance of the glass panel [W/m^{2}K]
- U_f: thermal transmittance of the frame [W/m^{2}K]
- ψ_g: linear thermal transmittance of the junction frame-glass [W/mK]
- A_g: area of the glass panel [m^2]
- A_f: area of the frame [m^2]
- l_g: length of the junction frame-glass [m]

To calculate the thermal transmittance of the glass we used the formulas described above, knowing that the window considered is double-glazed (4 mm thick each) and has an air cavity of 15 mm.

The thermal transmittance obtained is:

$$U_g = 1.33 \left[\frac{W}{m^2 * K}\right]$$

Calculation of the thermal transmittance of the Glass Panels

N. Glass Panels	Thickness [m]	Thermal conductivity λ [W/m*K]	Thermal resistance R [m²*K/W]
1	0.004	1.00	0.004
2	0.004	1.00	0.004
3	/	/	0.000

N. Cavities	Thickness [m]	Thermal conductivity λ [W/m*K]	Thermal resistance R [m²*K/W]
1	0.015	0.026	0.577
2	/	/	0.00
3	/	/	0.00

Thermal resistance R_{TOT} [m²*K/W] (glass panels)	Thermal resistance R_{TOT} [m²*K/W] (cavities)
0.01	0.58

Ug_{TOT} [W/m²K]	Rg_{TOT} [m²K/W]	Total Thermal conductivity λ [W/m*K]	Total Thickness b_g [m]
1.33	0.75	0.03	0.023

Table 4.3_ Calculation of glass panels thermal transmittance

To calculate the thermal transmittance of the frame we followed the EN ISO 10077:

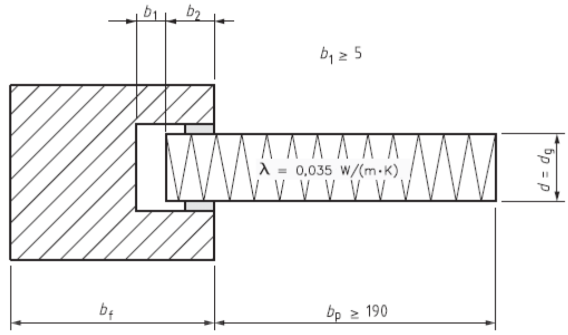


Figure 4.48_ Schematization of the window node from EN ISO 10077 – STEP 1

We supposed that the windows have a wooden frame.

As a first step, we modelled the window in Grasshopper. The THERM component contained in Honeybee (a Grasshopper plug-in) allowed us to analyse the node directly on our mean software.

Following the code, we have **replaced the glass panels with an insulation panel (λ=0.035 W/mK).** In this way, we obtained the value of thermal conductance of the section L_f^{2D}:

$$L_f^{2D} = 1.36 \text{ W/mK}$$

From this value we can find the thermal transmittance of the frame:

$$U_f = \frac{L_f^{2D} - U_p b_p}{b_f}$$

With:

- U_p is the thermal transmittance of the panel [W/m²K];
- b_p is the length of the panel (≥ 0.19 m) [m];
- b_f is the length of the frame [m].

As a second step we modelled the glass panel as an equivalent glass panel setting as conductivity λ=0.0306 W/mK (calculated knowing the thermal transmittance and the thickness of the glass panel) and calculating the new thermal conductance of the section:

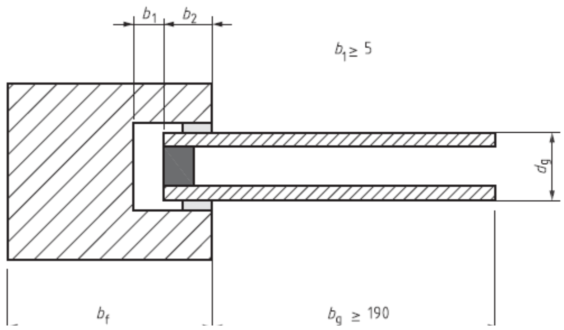


Figure 4.49_ Schematization of the window node from EN ISO 10077 – STEP 2

$$L_Y^{2D} = 1.50 \text{ W/mK}$$

Thanks to this value we can calculate the linear thermal transmittance:

$$\psi_g = L_Y^{2D} - U_f b_f - U_g b_g$$

In this approximate calculation, we have decided to **neglect the value of $\boldsymbol{\psi_g}$** for the calculation of U_W.

Calculation of the thermal transmittance of the frame + Ψ							
Follow the EN ISO 10077							

BOTTOM

INSULATION PANEL (λ=0.035 W/m*K)	Heat flow [W]	Length b [m]
Frame	3.55	0.07
Insulation Panel	30.55	1.00

EQUIVALENT GLASS PANEL	Heat flow [W]	Length b [m]
Frame	3.79	0.07
Equivalent Glass	33.71	1.00

Ug_{TOT} [W/m²K]	Total Thickness b_g [m]
1.33	0.02

Thermal conductance of the section L_f^{2D} [W/m*K]	Thermal transmittance U_{frame} [W/m²*K]	Thermal conductance of the section L_Ψ^{2D} [W/m*K]	Linear thermal transmittance Ψ [W/m*K]
1.36	1.97	1.50	0.024

LATERAL

INSULATION PANEL (λ=0.035 W/m*K)	Heat flow [W]	Length b [m]
Frame	6.15	0.12
Insulation Panel	30.54	1.00

EQUIVALENT GLASS PANEL	Heat flow [W]	Length b [m]
Frame	6.35	0.12
Equivalent Glass	33.72	1.00

Ug_{TOT} [W/m²K]	Total Thickness b_g [m]
1.33	0.023

Thermal conductance of the section L_f^{2D} [W/m*K]	Thermal transmittance U_{frame} [W/m²*K]	Thermal conductance of the section L_Ψ^{2D} [W/m*K]	Linear thermal transmittance Ψ [W/m*K]
1.47	2.06	1.60	0.023

Table 4.4_ Calculation of the thermal transmittance of the frame

Now we have all the values to insert in the formula for the window thermal transmittance calculation:

$$U_W = \frac{\sum A_g U_g + \sum A_f U_f + \sum l_g \psi_g}{A_f + A_g}$$

$$U_W = 1.52 \text{ W/m}^2\text{K}$$

Milan is located in climatic zone E and according to the legislation "*Nuovi Criteri Ambientali Minimi*" (CAM) and to the new *D.M.*, the maximum acceptable value is:

$$U_{W_{MAX}} = 1.40 \text{ W/m}^2\text{K}$$

This means that a window like the one just analyzed cannot be sold nowadays. As mentioned, ***we did not intervene on the transparent surfaces***: we could suppose that these elements have been already requalified in the early 2000s, that is why the client doesn't want to have a second intervention on it.

FINAL CALCULATION OF Uw		
	BOTTOM	LATERAL
FRAME		
Thermal transmittance U_{frame} [W/m²*K]	1.97	2.06
Length b [m]	0.07	0.12
Length f [m]	1.80	1.30
Area Af [m²]	0.13	0.16
	$\Sigma U_f * A_f$ [W/K]	1.15
Thermal Bridges		
Thermal conductance of the section L_Ψ^{2D} [W/m*K]	1.50	1.60
Linear thermal transmittance Ψ [W/m*K]	0.02	0.02
Length [m]	1.56	1.16
	$\Sigma L_\Psi^{2D} * \Psi$ [W/m*K]	0.13
Glass		
Ug_{TOT} [W/m²K]	1.33	
Ag [m²]	1.80	
	$\Sigma U_g * A_g$ [W/K]	2.41
FINAL CALCULATION OF Uw		
	A_w [m²]	2.34
	U_w [W/m²*K]	1.52

Table 4.5_ Final calculation of Uw

Hygrothermal behaviour

In the sheet "*6_Therm-Hygrometric*" of the reference Excel document, the Glazer Diagram was used to evaluate the hygrometric behaviour of the wall, in order to identify any interstitial condensation problems. To do this, we calculated:

- The thermal conductivity and vapour permeability of every single layer;
- The temperatures at the interfaces between two adjacent layers;
- The saturation pressures of the water vapour and the partial pressures of the steam.

If the partial pressure value were greater than that of the saturation pressure, we would have had problems with interstitial condensation.

Also in this document, the thermal transmittances of the configurations are highlighted.

If the maximum limits by normative are not respected, the document clearly warns us with the message "NOT OK". In the same way, the possible presence of interstitial condensation is indicated.

The maximum limits of thermal transmittance are the following (our case study is in climate zone E):

	Reference Building Parameters U_{ref} [W/m^2*K]				
Climate Zones	Vertical Wall	Roof	Floor	Windows	Party Wall
A-B	0.43	0.35	0.44	3	0.8
C	0.34	0.33	0.38	2.2	0.8
D	0.29	0.26	0.29	1.8	0.8
E	0.26	0.22	0.26	1.4	0.8
F	0.24	0.2	0.24	1.1	0.8

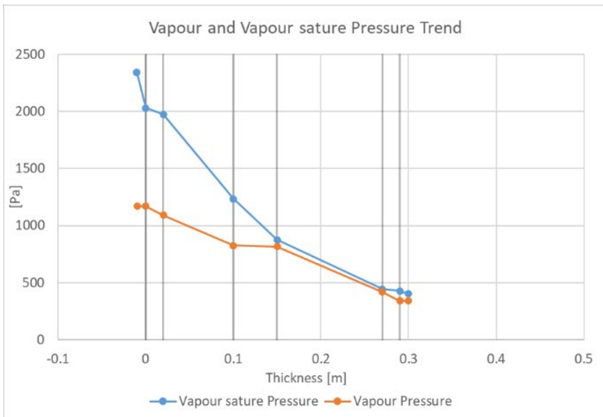
Table 4.6_ Maximum limits of thermal transmittance

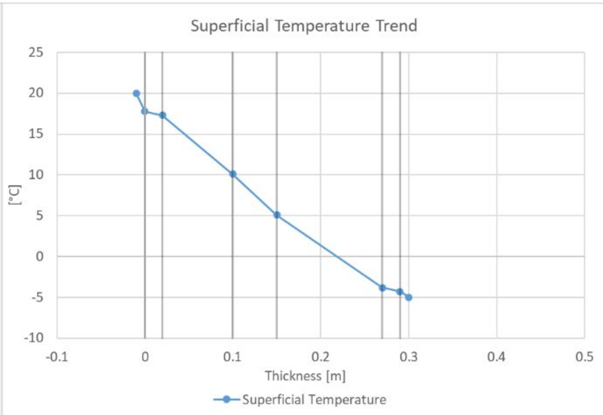
The behaviour of each configuration is easily understood thanks to the tables and graphs below.

	CV01 - BASE CASE							
	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	17.75	$P_{VS,S,INT}$	2030.15	$P_{V,S,INT}$	1168.48	OK
1-2	0.02	T_1	17.30	$P_{VS,1}$	1973.22	$P_{V,1}$	1090.06	OK
2-3	0.1	T_2	10.08	$P_{VS,2}$	1234.21	$P_{V,2}$	825.93	OK
3-4	0.15	T_3	5.08	$P_{VS,3}$	876.47	$P_{V,3}$	815.61	OK
4-5	0.27	T_4	-3.83	$P_{VS,4}$	443.31	$P_{V,4}$	419.42	OK
5	0.29	$T_{S,EST}$	-4.28	$P_{VS,S,EST}$	426.65	$P_{V,S,EST}$	341.00	OK
EXT	0.3	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

R_{TOT} [m^2*K/W]	1.39	U [W/m^2*K]	0.72
φ [W/m^2]	18.03		NOT OK
$Thickness_{TOT}$ [m]	0.29		

Z_{TOT} [Pa*s*m^2/kg]	2.01E+10
G [kg/m^2*s]	4.13E-08
δ_0 [kg/Pa*s*m]	2.00E-10



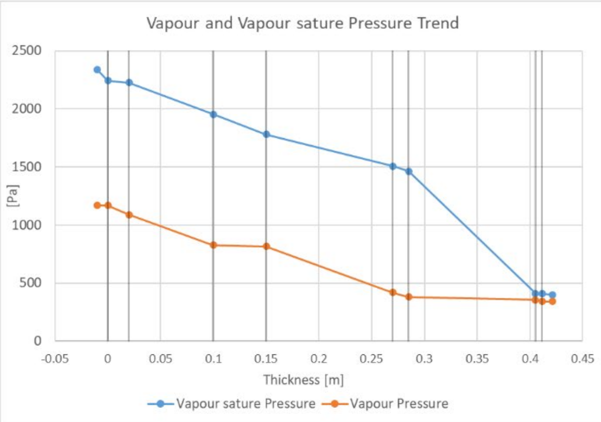


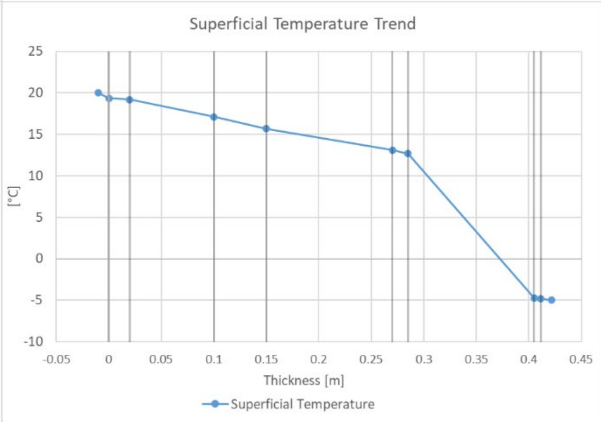
In this case, we can notice how the original perimetral wall (CV01-BASE CASE) has a thermal transmittance well beyond the allowed limit (U_{lim}=0.26 W/m^{2}K), however, it does not have interstitial condensation problems.

	CV02 - BASE CASE + INSULATION								
	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	19.35	$P_{VS,S,INT}$	2244.23	$P_{V,S,INT}$	1168.48	OK
1-2	0.02	T_1	19.22	$P_{VS,1}$	2226.08	$P_{V,1}$	1090.02	OK
2-3	0.10	T_2	17.13	$P_{VS,2}$	1952.60	$P_{V,2}$	825.76	OK
3-4	0.15	T_3	15.68	$P_{VS,3}$	1780.44	$P_{V,3}$	815.44	OK
4-5	0.27	T_4	13.10	$P_{VS,4}$	1507.01	$P_{V,4}$	419.04	OK
5-6	0.29	T_5	12.67	$P_{VS,5}$	1464.71	$P_{V,5}$	381.88	OK
6-7	0.41	T_6	-4.73	$P_{VS,6}$	410.57	$P_{V,6}$	357.11	OK
7	0.41	$T_{S,EST}$	-4.79	$P_{VS,S,EST}$	408.41	$P_{V,S,EST}$	341.00	OK
EXT	0.42	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

R_{TOT} [m^2*K/W]	4.79	U [W/m^2*K]	0.21
φ [W/m^2]	5.22		OK
$Thickness_{TOT}$ [m]	0.41		

Z_{TOT} [Pa*s*m^2/kg]	2.00E+10
G [kg/m^2*s]	4.13E-08
δ_0 [kg/Pa*s*m]	2.00E-10

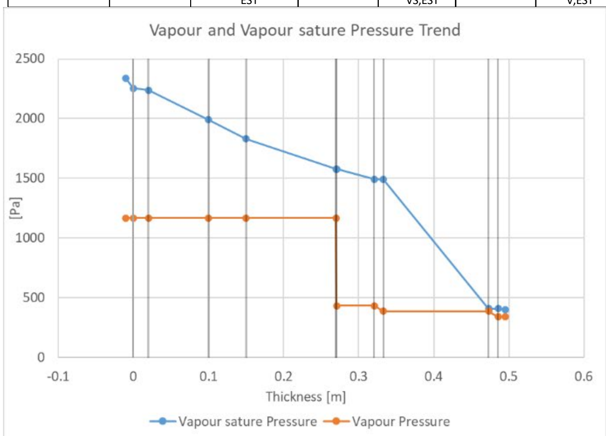


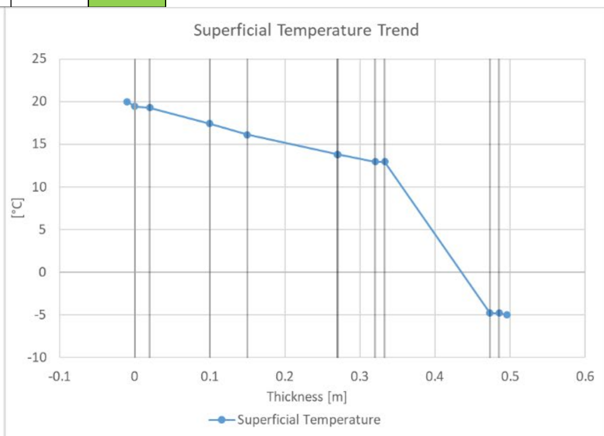


	CV06 - EASEE Panel								
	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	19.41	$P_{VS,S,INT}$	2253.63	$P_{V,S,INT}$	1168.48	OK
1-2	0.02	T_1	19.30	$P_{VS,1}$	2237.29	$P_{V,1}$	1168.38	OK
2-3	0.10	T_2	17.43	$P_{VS,2}$	1989.46	$P_{V,2}$	1168.07	OK
3-4	0.15	T_3	16.12	$P_{VS,3}$	1831.83	$P_{V,3}$	1168.06	OK
4-5	0.27	T_4	13.81	$P_{VS,4}$	1578.47	$P_{V,4}$	1167.59	OK
5-6	0.27	T_5	13.80	$P_{VS,5}$	1577.49	$P_{V,5}$	433.77	OK
6-7	0.32	T_6	12.96	$P_{VS,6}$	1492.91	$P_{V,6}$	433.76	OK
7-8	0.33	T_7	12.93	$P_{VS,7}$	1490.06	$P_{V,7}$	387.89	OK
8-9	0.47	T_8	-4.78	$P_{VS,8}$	408.68	$P_{V,8}$	386.87	OK
9-10	0.49	T_9	-4.81	$P_{VS,9}$	407.66	$P_{V,9}$	341.00	OK
EXT	0.50	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

R_{TOT} [m^2*K/W]	5.34	U [W/m^2*K]	0.19
φ [W/m^2]	4.68		OK
$Thickness_{TOT}$ [m]	0.49		

Z_{TOT} [Pa*s*m^2/kg]	1.69E+13
G [kg/m^2*s]	4.89E-11
δ_0 [kg/Pa*s*m]	2.00E-10



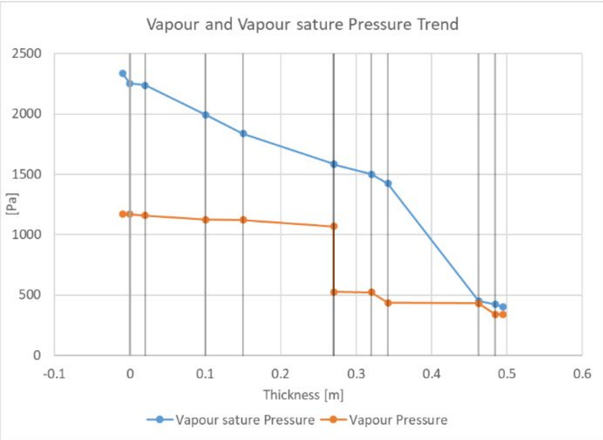


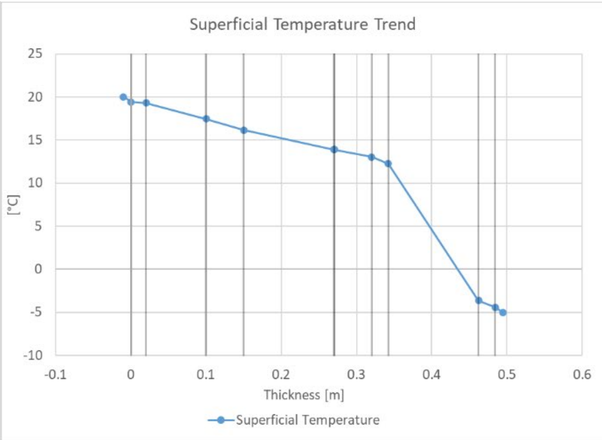
In the EASEE configuration, it was necessary to add a vapour barrier to avoid interstitial condensation problems.

	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
	CV04 - TES WOOD PANEL							
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	19.42	$P_{VS,S,INT}$	2254.47	$P_{V,S,INT}$	1168.48	OK
1-2	0.02	T_1	19.30	$P_{VS,1}$	2238.28	$P_{V,1}$	1158.13	OK
2-3	0.10	T_2	17.45	$P_{VS,2}$	1992.77	$P_{V,2}$	1123.29	OK
3-4	0.15	T_3	16.16	$P_{VS,3}$	1836.46	$P_{V,3}$	1121.93	OK
4-5	0.27	T_4	13.88	$P_{VS,4}$	1584.96	$P_{V,4}$	1069.67	OK
5-6	0.27	T_5	13.87	$P_{VS,5}$	1584.31	$P_{V,5}$	525.28	OK
6-7	0.32	T_6	13.03	$P_{VS,6}$	1500.26	$P_{V,6}$	523.92	OK
7-8	0.34	T_7	12.25	$P_{VS,7}$	1425.04	$P_{V,7}$	434.09	OK
8-9	0.46	T_8	-3.64	$P_{VS,8}$	450.56	$P_{V,8}$	430.83	OK
9	0.48	$T_{S,EST}$	-4.42	$P_{VS,S,EST}$	421.52	$P_{V,S,EST}$	341.00	OK
EXT	0.49	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

R_{TOT} [m^2*K/W]	5.40	U [W/m^2*K]	0.19
φ [W/m^2]	4.63		OK
Thickness$_{TOT}$ [m]	0.56		

Z_{TOT} [Pa*s*m^2/kg]	1.52E+11
G [kg/m^2*s]	5.44E-09
δ_0 [kg/Pa*s*m]	2.00E-10



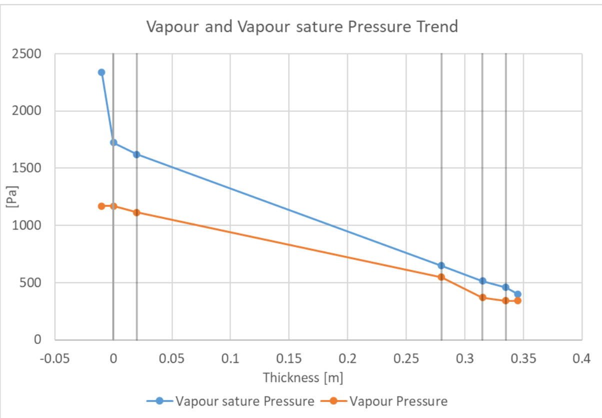


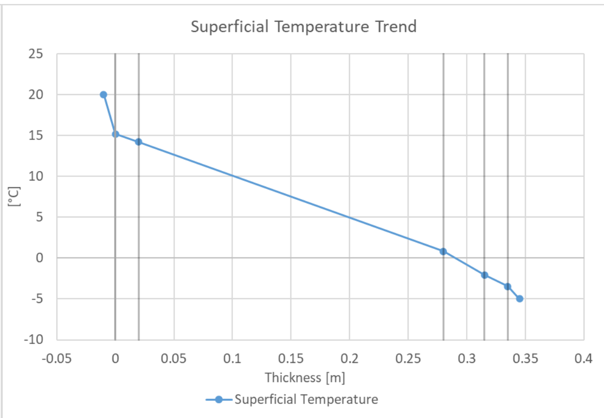
Instead, In the TES configuration, it was necessary to add a vapour retarder to avoid interstitial condensation problems.

	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
	CO01 - ROOF BASE CASE							
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	15.17	$P_{VS,S,INT}$	1723.56	$P_{V,S,INT}$	1168.48	OK
1-2	0.02	T_1	14.21	$P_{VS,1}$	1619.47	$P_{V,1}$	1113.36	OK
2-3	0.28	T_2	0.82	$P_{VS,2}$	648.08	$P_{V,2}$	547.69	OK
3-4	0.315	T_3	-2.05	$P_{VS,3}$	514.88	$P_{V,3}$	370.01	OK
4	0.335	$T_{S,EST}$	-3.46	$P_{VS,S,EST}$	457.52	$P_{V,S,EST}$	341.00	OK
EXT	0.345	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

R_{TOT} [m^2*K/W]	0.65	U [W/m^2*K]	1.54
φ [W/m^2]	38.61		NOT OK
Thickness$_{TOT}$ [m]	0.34		

Z_{TOT} [Pa*s*m^2/kg]	2.85E+10
G [kg/m^2*s]	2.90E-08
δ_0 [kg/Pa*s*m]	2.00E-10

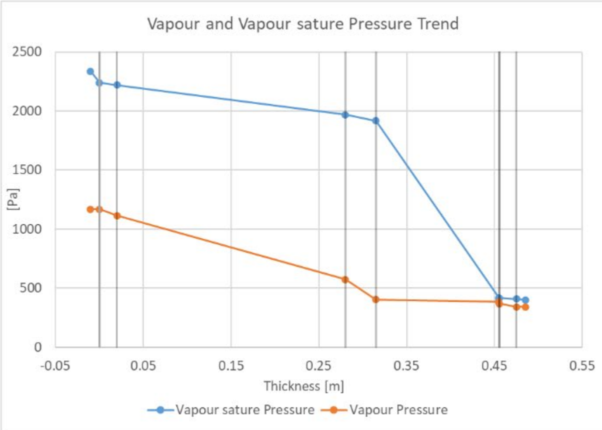


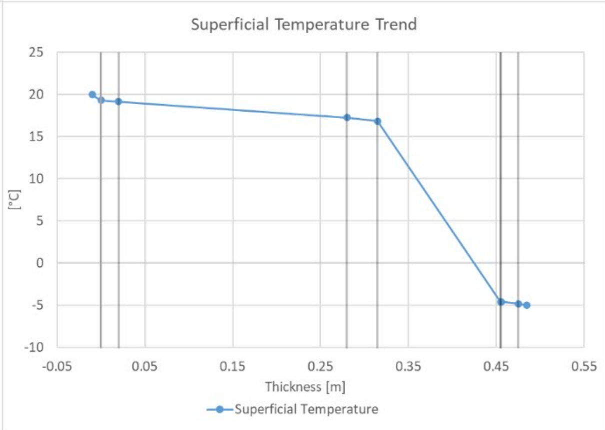


Also the original roof (CO01-ROOF BASE CASE), like the perimetral wall, has a thermal transmittance much higher than the allowed limit (U_{lim}=0.22 W/m^{2}K). The new configuration shown below respects both thermal and hygrometric properties.

CO03 - ROOF BASE CASE + INSULATION								
	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	19.31	$P_{VS,S,INT}$	2239.21	$P_{V,S,INT}$	1168.48	OK
1-2	0.02	T_1	19.17	$P_{VS,1}$	2220.09	$P_{V,1}$	1115.59	OK
2-3	0.28	T_2	17.26	$P_{VS,2}$	1969.38	$P_{V,2}$	572.76	OK
3-4	0.32	T_3	16.85	$P_{VS,3}$	1918.89	$P_{V,3}$	402.26	OK
4-5	0.46	T_4	-4.56	$P_{VS,4}$	416.48	$P_{V,4}$	382.77	OK
5-6	0.46	T_5	-4.58	$P_{VS,5}$	415.86	$P_{V,5}$	368.84	OK
6	0.48	$T_{S,EST}$	-4.78	$P_{VS,S,EST}$	408.81	$P_{V,S,EST}$	341.00	OK
EXT	0.49	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

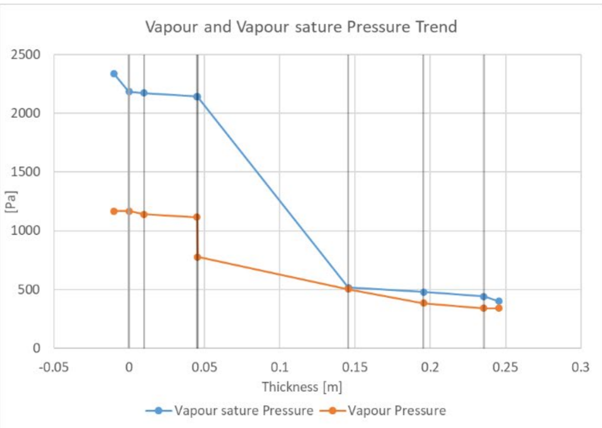
R_{TOT} [m^2*K/W]	4.54	U [W/m^2*K]	0.22
φ [W/m^2]	5.51		OK
$Thickness_{TOT}$ [m]	0.48		
Z_{TOT} [Pa*s*m^2/kg]	2.97E+10		
G [kg/m^2*s]	2.78E-08		
$δ_0$ [kg/Pa*s*m]	2.00E-10		

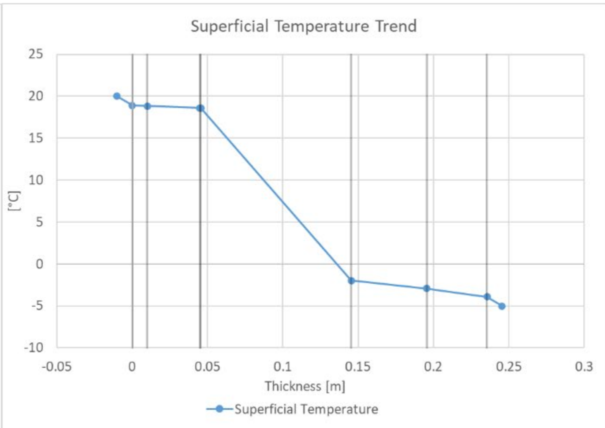




CO02 - BASEMENT BASE CASE								
	Thickness [m]	Superficial Temperature	[°C]	Vapour sature Pressure	[Pa]	Vapour Pressure	[Pa]	
INT	-0.01	T_{INT}	20.00	$P_{VS,INT}$	2336.95	$P_{V,INT}$	1168.48	OK
1	0	$T_{S,INT}$	18.92	$P_{VS,S,INT}$	2185.16	$P_{V,S,INT}$	1168.48	OK
1-2	0.01	T_1	18.83	$P_{VS,1}$	2173.40	$P_{V,1}$	1141.21	OK
2-3	0.05	T_2	18.62	$P_{VS,2}$	2144.24	$P_{V,2}$	1117.36	OK
3-4	0.05	T_3	18.60	$P_{VS,3}$	2141.34	$P_{V,3}$	776.55	OK
4-5	0.15	T_4	-1.98	$P_{VS,4}$	517.83	$P_{V,4}$	503.91	OK
5-6	0.20	T_5	-2.90	$P_{VS,5}$	479.37	$P_{V,5}$	384.63	OK
6	0.24	$T_{S,EST}$	-3.92	$P_{VS,S,EST}$	439.88	$P_{V,S,EST}$	341.00	OK
EXT	0.25	T_{EST}	-5.00	$P_{VS,EST}$	401.18	$P_{V,EST}$	341.00	OK

R_{TOT} [m^2*K/W]	2.89	U [W/m^2*K]	0.35
φ [W/m^2]	8.64		NOT OK
$Thickness_{TOT}$ [m]	0.59		
Z_{TOT} [Pa*s*m^2/kg]	6.07E+10		
G [kg/m^2*s]	1.36E-08		
$δ_0$ [kg/Pa*s*m]	2.00E-10		





Geometry definition

CHAPTER'S SUMMARY:

In this chapter we will explain how the geometries and constraints imported on the parametric modelling software come together to allow the paneling of the surfaces according to the criteria chosen for each solution (ETICS, EASEE, TES). A three-dimensional preview of the panels with management of the corners is then presented, as well as a catalogue to assign a label to each panel.

In the first two sheets of the reference Excel file, "*1_Constraints_TES*" and "*2_Constraints_EASEE*", it is possible to insert the dimensional limits of the panels of the two prefabricated configurations we are analyzing. The advantage of using an Excel document is given by the possibility of making the information accessible to the various users of the project. In this section you have the possibility to collect the dimensional preferences according to various charges, starting from:

- Transport: limits due to the capacity of the means of transport chosen for handling the panels on-site,
- Producer: limits due to the maximum dimensions that the producer is able to realize;
- Architect: limits due to the architect's aesthetic preferences;
- Structure…

It is also possible to set a relationship between the width and height of the panel (L/H ratio) if required.

For the purposes of our analysis, for both configurations, we have chosen as the maximum limit the more restrictive among those reported in the Excel sheet.

EASEE Panel

CONSTRAINTS	max WIDTH [m]	max HEIGTH [m]	Ratio
L/H RATIO	/	/	0.1
TRANSPORT	2.30	12.00	/
PRODUCER	2.00	6.00	/
ARCHITECT	2.00	4.00	/

TES Wood Panel

CONSTRAINTS	max WIDTH [m]	min Width [m]	Ratio
L/H RATIO	/	/	/
TRANSPORT	12.00	2.30	/
PRODUCER	18.00	5.00	/
ARCHITECT	25.00	1.00	/

Table 4.7_ Dimensional constraints of the prefabricated panels

At this point of our study, we have all the information necessary to be able to panel our building:

- Geometries (surfaces) that we want to panel;
- Dimensional constraints of our panels (width, height, thickness, weight);
- Energy performance of the configurations.

The goal was to have a digital model that not only shows the panels according to the rules we have established but also automatically creates a material catalogue in order to categorize the types according to size, orientation and level.

To obtain all this information, a thorough discretization of the building is required.

Preparation of the geometry

First, **we created a digital bridge between Excel and Grasshopper**, so that if the dimensional constraints of our panels (defined in Excel) were changed, they would update our model (contained in Grasshopper) in real-time. This was possible thanks to the "*Read Excel Sheet*" component of a Grasshopper plug-in: *TT Toolbox (by CORE Studio)*[71].

At the same time, we intervened on the surfaces that we want to panel (see Chapter 4.2 "*Export from Revit*"). To better manage the future steps of our study regarding the extrusion of the panels and the definition of the catalogue, we have organized the opaque **surfaces** and windows in two ways:

- **Classified by facade (orientation);**
- **Classified by floor.**

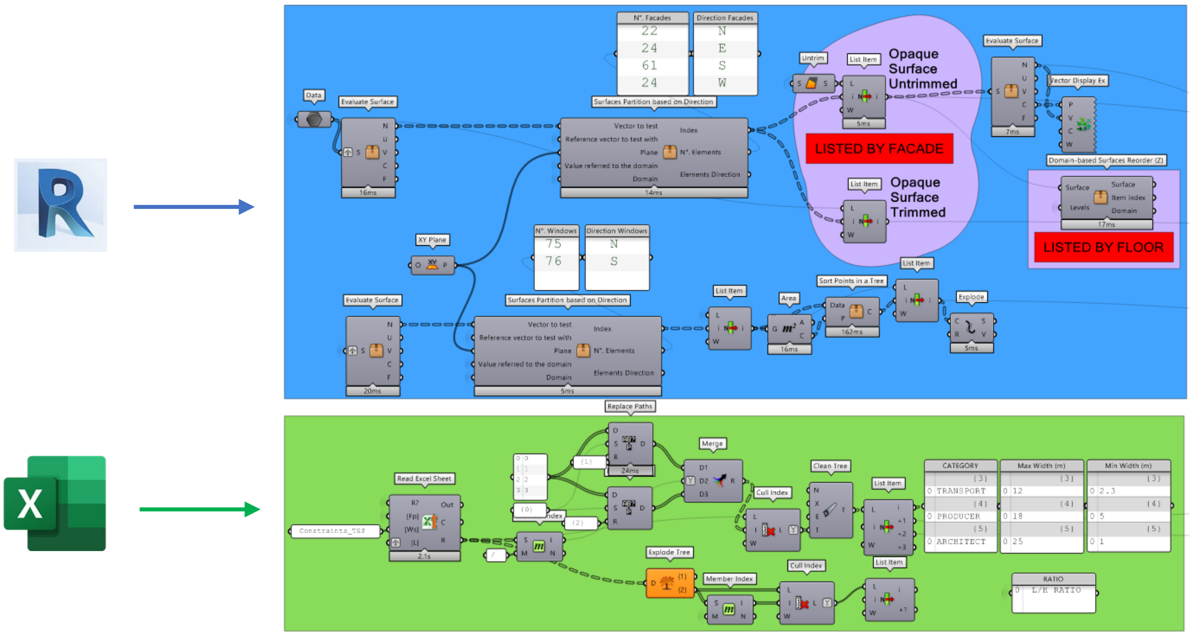


Figure 4.50_ Script section in which data are inserted from Excel and Revit.

Panelization

ETICS

The ETICS system does **not include prefabricated panels**, so we directly proceeded to extrude the under-renovation surfaces to obtain the final model (see next Chapter "*Extrusion*").

EASEE

The EASEE configuration turned out to be the most complex to model since the panels do not include the windows which therefore proved to be an additional obstacle to be considered.

After having tested different procedures with which to panel the surfaces (i.e., "*Catmull-Clark*" in Chapter 4.2 "*2D Modeling - Rhino*"), the most appropriate choice turned out to be in **dividing the surfaces by submultiples of the length** taken into consideration (width and/or height).

As a first step, to overcome the problem of windows that we don't have to consider, we have reconstructed the **surfaces** to be panelled by **separating** them **into 2 macro-areas**:

- **Areas between two windows;**
- **Areas above-under the window.**

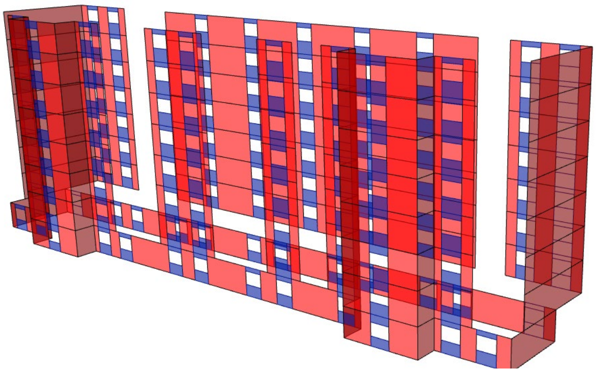


Figure 4.51_ Schematization of the 2 macro areas: space between windows (red), area above-under the windows (blue).

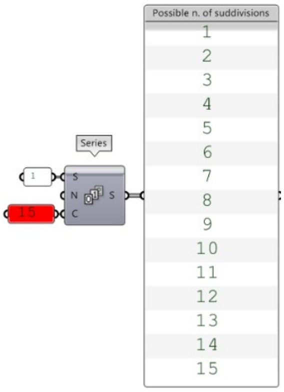


Figure 4.52_ Number of subdivisions of the surfaces.

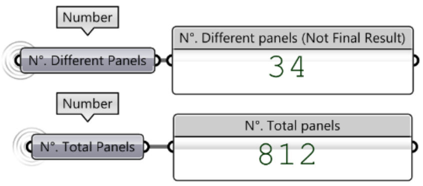
At this point, we proceeded to divide each of these macro-areas by submultiples. The script contains the dimensions that each panel would have if the surfaces were divided from one to 15 times.

The **dimensional constraints**, therefore, made it possible to **filter the possible configurations** while keeping only those included within the defined limits. It is also possible to insert a lower limit that defines the minimum acceptable size of our panel.

As a result, we got:

- **a first layout of the arrangement of the panels in 2D;**
- **the total number of panels;**
- **a first, NOT FINAL, estimate of the number of different panels.**

The number of different panels is not yet the definitive one since at this stage the discussion of the nodes at the corners of the building has not yet been managed, which affects the size of the two panels that converge, depending on the priorities defined. This aspect has been dealt with in the "*Extrusion*" section.



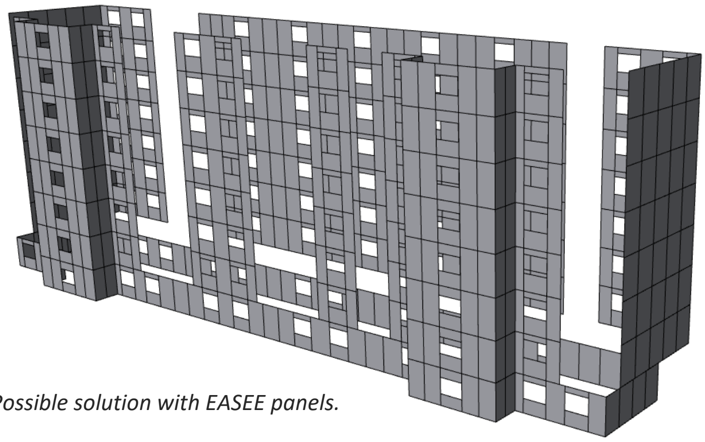


Figure 4.53_ Possible solution with EASEE panels.

TES

The TES configuration has the advantage that it can cover larger sizes than the EASEE solution. In addition, this prefabricated panel can also accommodate windows, or as in our case (since the windows have not been redeveloped) a simple opening.

In this case, it was not necessary to divide the surfaces into three macro-areas, but the conditions to be met were: do not match the joints of the panels where there are windows, do not exceed the constraints defined in the Excel.

However, we found a further complication that did not occur in the EASEE configuration: when we went to move the line that defines the joint between two adjacent panels, we needed to also move the next lines in an iterative way, otherwise, we would no longer have respected the dimensional limits imposed. But this was not an easy job considering that the obstacle of the windows made the process more complex. To overcome this problem, it was decided to opt for a solution that always has a joint between two windows, even when perhaps our dimensional constraints would have allowed us to have two openings on a single prefabricated panel.

The script allows you to move the joint along the distance between two windows. So, what **we expect** from the results is to always **have the same total number of panels**, but the **possibility of varying the total number of different panels**.

Furthermore, unlike the EASEE configuration in which the solutions that exceeded the constraints were eliminated previously, in this case, we have the **possibility to verify** thanks to a panel if and **how many panels** there are that **do not respect the imposed limits**.

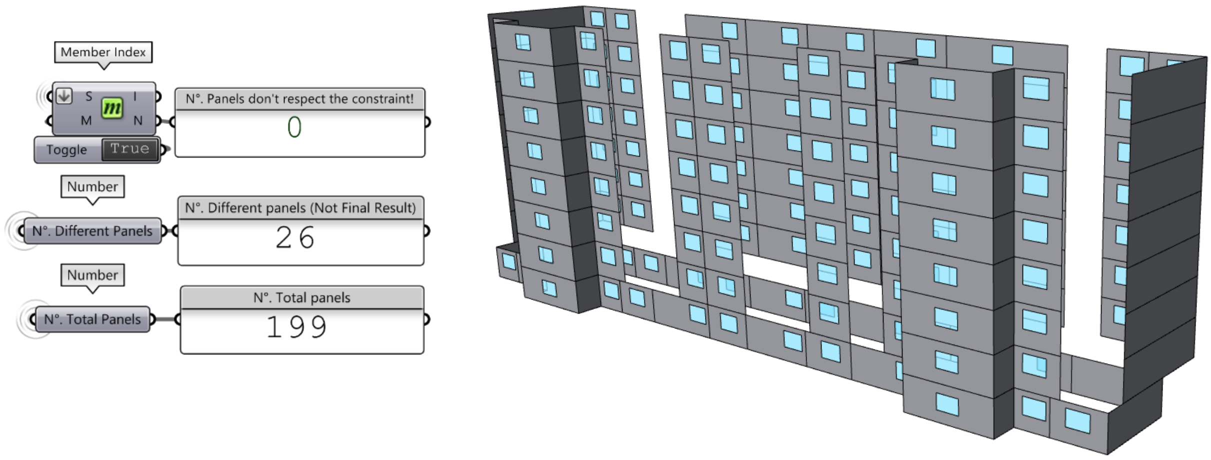


Figure 4.54_ Possible solution with TES panels.

Extrusion

After obtaining the panels in 2D, we proceeded with the **correction of the details** of the individual elements.

The intervention concerned:

- **Correction of the dimensions of the panels in the corners of the building (priority management).**
- **Correction of the gaps between the panels throughout the building.**

ETICS

The ETICS system doesn't require facade panelling, so it was not necessary to create any gaps. We proceeded with extruding the surfaces considering the previously defined thicknesses and correcting the angles to ensure that the insulation remained continuous over the entire wall, avoiding linear thermal bridges.

EASEE

The EASEE configuration has more peculiarities. Also, in this case, the first step was to **extrude the surfaces** according to the defined thicknesses; subsequently, the **gaps between the different panels** were developed to allow them to move when forces are acting and to avoid problems due to dilatations.

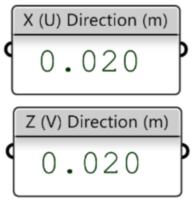


Figure 4.55_ Size of the gaps between two neighbouring panels.

At this point, we can **isolate** all the panels in the convex and/or concave **corners** of the building **and then proceed with node management.**

There are **3 different solutions:**

- **90° cut giving priority to North/South oriented panels;**
- **90° cut giving priority to East/West oriented panels;**
- **45° cut.**

Since this configuration is a prefabricated sandwich panel, much more compact than the TES solution, it is possible to make a 45° cut if necessary.

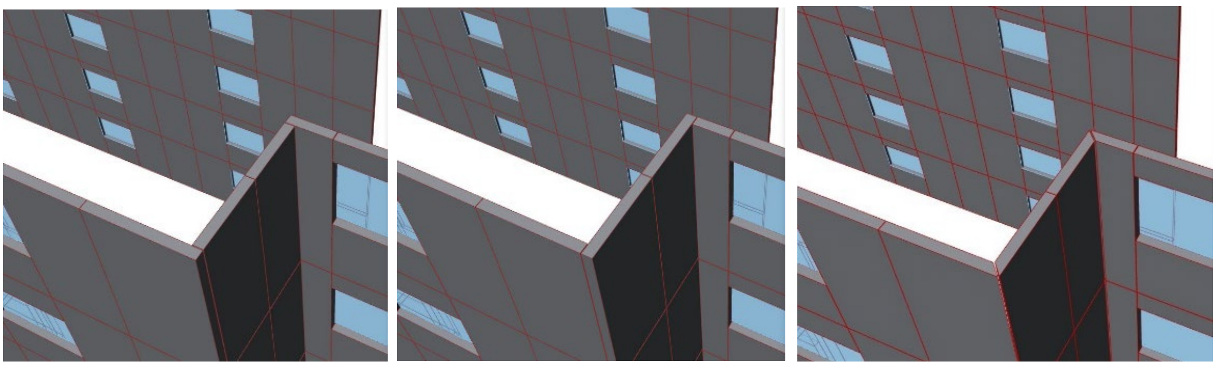


Figure 4.56_ Different types of node cut: 90°_priority N/S (left), 90°_priority E/W (centre), 45° (right).

TES

The TES configuration was developed following the same steps treated for the EASEE solution with the only difference that the **joints of the panels in the corners of the building only have a 90° cut**.

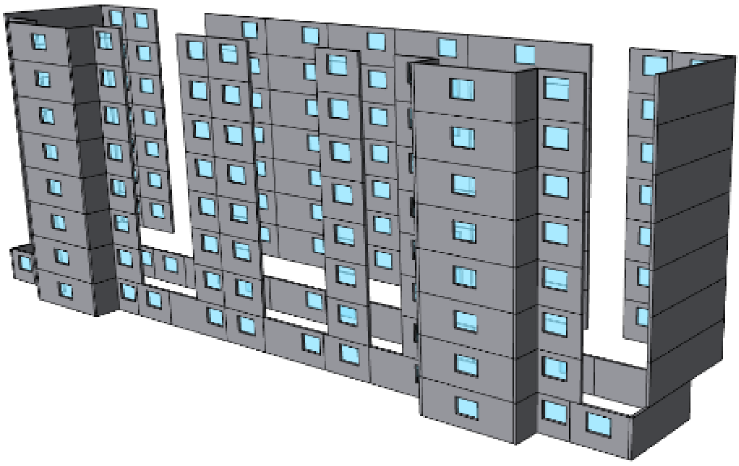


Figure 4.57_ TES model with 3D panels.

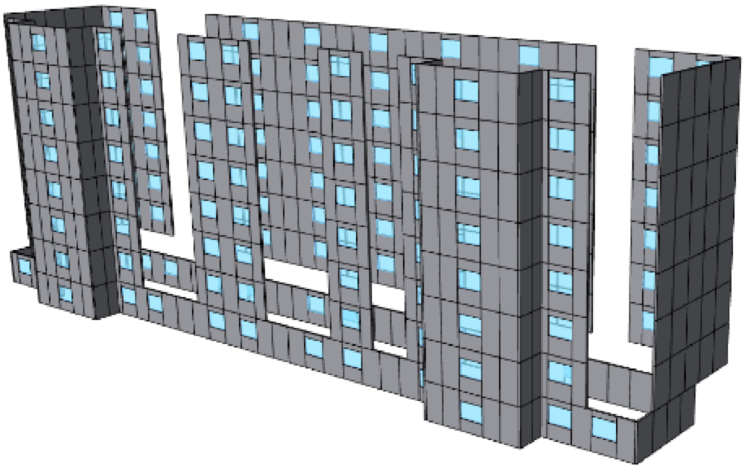


Figure 4.58_ EASEE model with 3D panels.

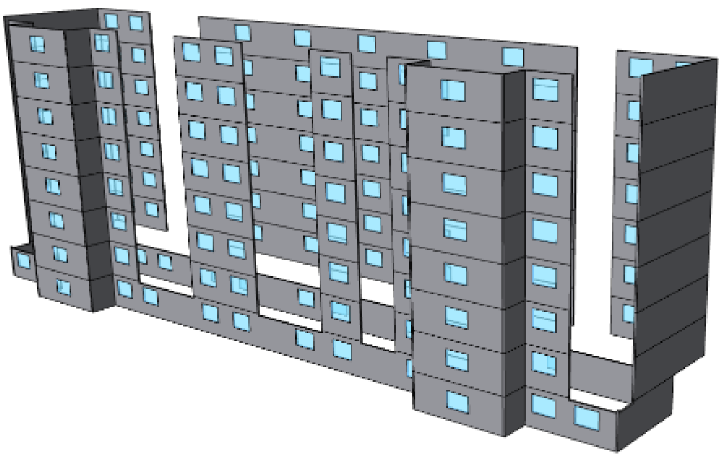


Figure 4.59_ ETICS model with geometries extruded.

Panels catalogue

Having obtained the final geometries of the panels, we have developed a script that is able to distinguish the different types of panels present in our building.

First, we derived the final dimensions of the panels, the total number of panels, and the number of different panels.

At this point, **we have created a label that defines a specific code for each panel, based on**:

Label sample

- **Orientation (N, E, S, W)** → **S** . T . 05 . 51
- **Type (A, B, C, D, E, F ...)** → S . **T** . 05 . 51
- **Floor level (00, 01, 02 ...)** → S . T . **05** . 51
- **Progressive (00, 01, 02…).** → S . T . 05 . **51**

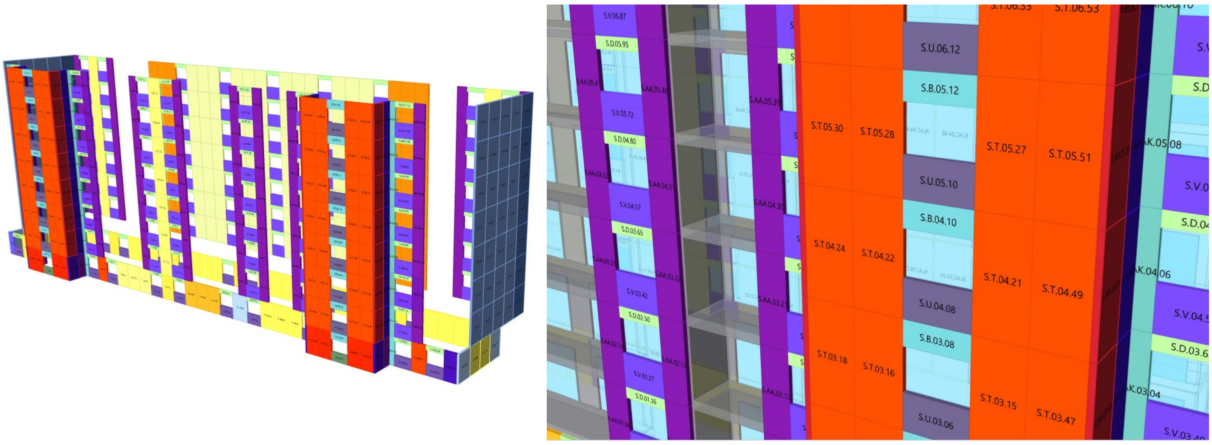


Figure 4.60_ 3D model with catalogue of the panels.

A different colour is assigned to each type of panel.

Thanks to the label it is possible to easily trace every single panel if there are problems with one of them.

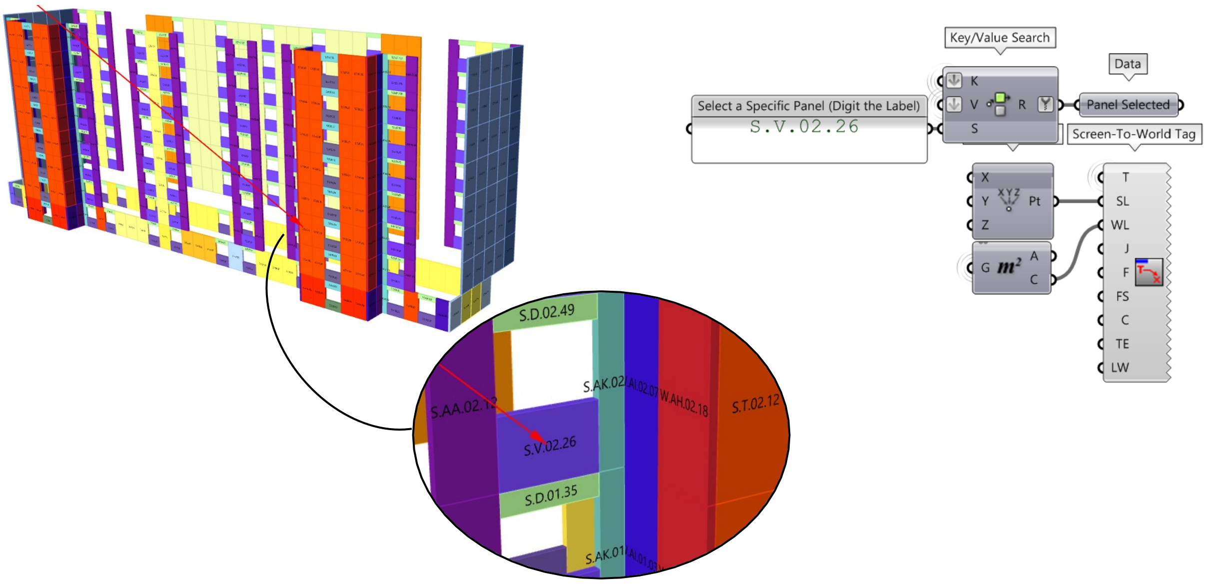


Figure 4.61_ Panel tracing thanks to the label.

Structures

CHAPTER'S SUMMARY:

For the structural analysis of these elements, evaluated in terms of the number of **anchors** needed to hold the different panels, we have tried to investigate the possibility as well of **collecting generic data** obtained within the parametric modeling software (or here brought again) to favor new evaluation keys on the choice to be made in the whole analysis. With this goal we developed an analysis that aimed to evaluate the **maximum deformation** reached under the design loads.

The concept of intervention on the existing heritage can include multiple solutions including insertion in place of the existing inter-floor or external envelope, positioning above the existing envelope or extension of the existing façade [15] :

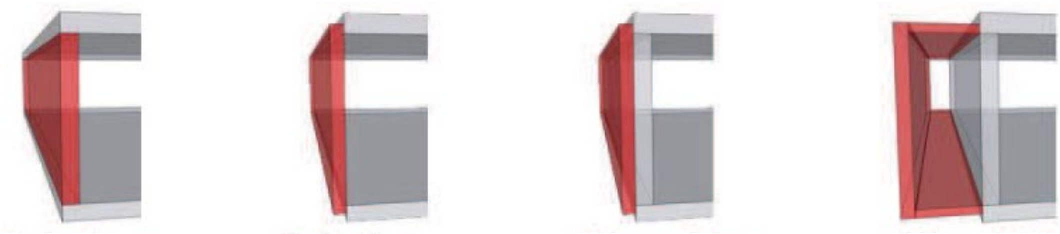


Figure 4.62_ Common strategies for systems on existing envelope
Credits: NaturWall _ multifunctional wood façade in existent building refurbishment

When we approach the topic of load-bearing structures, two different scenarios can emerge [18] :

- the **existing structure** is capable of supporting loads of the new facade system;
- the existing structure is unable to support loads of the new facade system.

If the case study falls into the second type, usually there is a tendency to create a load distribution substructure or to create the new façade system as a self-standing construction. However, given the complexity of creating a system based on these principles, as well as the fact that this approach goes beyond the creation of a decision support tool, it was decided to consider the first of the two possible configurations to be true. Moreover, as we mentioned, the following report does not aim at the structural verification of the real capacity of the building's structural system, therefore we would not have the possibility to verify whether the added loads involve excessive overload on the existing beams or not. For this reason, for the types of **prefabricated panels EASEE and TES**, we opted for a system with point/linear fastening to the main load-bearing elements of the old building, from floor to floor.

As *for the **dimensions of the modules***, here too there are more possible scenarios, and they range from constructions made single-span beam or continuous beam construction. While modules higher than a level are difficult to implement (transport, lifting, etc.), a possible solution would be to create modules as high as the building facade, but with limited width according to specific criteria. This second approach also guarantees better performance for supporting the loads, as the intermediate floors are mainly made of brick-cement slabs with a beam grid, therefore with a significantly higher bearing capacity. On the other hand, a module that goes beyond the inter-storey dimensions, in addition to the problems mentioned above, must necessarily hook onto the wall of the old building.

	Single-span beam construction Module system is mounted directly on subsurface or upon substructure	**Continuous beam construction** Continuous beam acts as substructure
Suspended construction	Fixed support on top 	Fixed support on top 
Standing construction	Fixed support at the bottom 	Fixed support at the bottom 
Evaluation	Modules have to be self-supporting. Additional substructure not mandatory. Without substructure every module has to be adjusted during assembling. Interchangeability of each module is possible.	Modules may be designed slimmer. Equalization of uneven subsurfaces by substructure. Assembling modules on substructures enables faster proceeding. Single modules are exchangeable.
Tolerances	Tolerances to allow movements emerging from temperature of each module.	Tolerances to allow movements emerging from temperature of each module.

Figure 4.63_ Single-span beam construction VS Continuous beam construction. Credits: Types of Buildings with Prefabricated Elements for (n)ZEB Performance.

This is how the **number/type of anchoring** and dimensions of the panel are **reciprocally influenced**.

Any system that increases the number of anchors (with less reciprocal space between them), therefore, optimally redistributes the load, improves the resistance to wind action, the free deflection length is reduced, etc. Furthermore, anchoring to a few points increases the risk of encountering weak points within the old structure due to the heterogeneity of the material, which is not the case if more anchors or even line supported fixing systems are provided. Finally, we must remember that every anchoring system must, in any case, absorb the movements and stresses caused by temperature, wind, earthquake, etc. so as not to compromise the whole solution.

Anchors

The analysis of the anchors was made starting from the load conditions to which the individual panels are subjected; two actions have been considered dominant:

1. Dead Load

   Considered along the global Z-axis and directed downwards, it was calculated starting from the Weight values per square meter of the façade (Kg/m^2) obtained during the study phase on the different stratigraphy solutions. It is useful to underline that the values taken refer only to the additions with respect to the base case, consisting of double brick infill stratigraphy.

   The values obtained are:

   - EASEE panel = 59.88 Kg/m^2
   - TES panel = 61.45 Kg/m^2.

2. Wind Loads

Taken along the normal outgoing direction at the face of the panel, it was calculated starting from the indications provided in the text of the *Norme Tecniche per le Costruzioni 2018* [72] and *Circolare Applicative* [73].

The wind exerts on the actions of the construction that vary over time and space causing, in general, dynamic effects; however, these actions may be traced back to equivalent static actions, as explicated below.

The value of the base reference velocity is given by the expression:

$$\mathrm{v_b} = \mathrm{v_{b,0}} \cdot \mathrm{c_a}$$

With:

- $\mathrm{v_{b,0}}$ base rate with reference at sea level
- $\mathrm{c_a}$ altitude coefficient provided by the relation:

  $c_a = 1$ For $\mathrm{a}_s \leq a_0$

  $c_a = 1 + k_s \left(\frac{a_s}{a_0} - 1\right)$ For $\mathrm{a_0} \leq a_s \leq 1500\ m$

The values of these parameters are defined in *Table 3.3.I* of the *NTC*, also considering that the zone to which it belongs is the 1 (Lombardia); we then get that:

Location zone	1 (Lombardia)
$\mathrm{v_{b,0}}$	25 m/s
$\mathrm{a_0}$	121 m
k_s	0,40
c_a	1 ($\mathrm{a}_s \leq a_0$)

The reference speed is therefore equal to:

$$v_b = v_{b,0} \cdot c_a = 27\ m/s$$

The average value over 10 minutes for the *Tempo di Ritorno* T_r (reference speed) is defined by the following relation:

$$v_r = v_b \cdot c_r$$

With:

- c_r return coefficient, a function of the project return period T_r (for T_r equal to 50 years corresponds to a value of $c_r = 1$).

So, the reference velocity value is assumed to be:

$$v_r = 27\ m/s$$

The kinetic reference pressure is given by the expression:

$$q_r = \frac{1}{2}\rho {v_r}^2 = 456\ N/m^2$$

Where:

- ρ is the air density, assumed 1.25 Kg/m^3

The coefficient of exposure c_e depends on the height z on the ground of the point in question, the topography of the soil and the category of exposure of the site where the construction is located; for height on the ground not greater than z = 200 m it is given by the formula:

$$c_e(z) = {k_r}^2 c_t \ln(z/z_0)[7 + c_t \ln(z/z_0)] \quad \text{For } z \geq z_{min}$$

$$c_e(z) = c_e(z_{min}) \quad \text{For } z < z_{min}$$

With:

- c_t topography coefficient generally placed equal to 1.

Assuming a roughness class of land A (Urban areas where at least 15% of the surface is covered by buildings with an average height of more than 15 m) and assuming a distance from the sea of more than 30 km, we obtain a category of site exposure equal to V and therefore:

Site exposure category	V
K_r	0.23
z_0	0.70 m
z_{min}	12 m

Since the project maximum z is 15.0 m, we have that:

$$z > z_{min} \rightarrow c_e(z) = 2.00$$

The dynamic coefficient (c_d) is placed cautiously equal to 1 because it belongs to constructions of a recurrent type.

As reported by the text of the Regulations, for the purposes of evaluating the external **pressure coefficient** (c_p)[73]:

In the following, with reference to the regular form constructions indicated in paragraphs C3.3.3.8.1 to C3.3.8.4, three distinct series of external pressure coefficients:

- global coefficients cp_e, which can be used in all cases where the representation of the aerodynamic actions of the wind can be carried out in a simplified way, aimed at the evaluation of global actions on extended portions of constructions or the resultants of the actions induced by the wind on the main elements of the structure;

- local coefficients cp_e, 10 allow a more realistic representation of the actual pressure field that is established on the surfaces of buildings and which can be used both as an alternative to the global pressure coefficients cp_e, and to quantify the local pressure on elements with an impact area greater than or equal to 10 m^2;

- local coefficients cp_e, 1 which allow the quantification of the local pressure on small elements with an area of incidence less than or equal to 1 m^2 (such as cladding elements and their fixings).

For the local pressure coefficients relating to an area of incidence between 1 and 10 m^2, the value is equal to:

$$cp_{e,A} = cp_{e,1} - (cp_{e,1} - cp_{e,10}) \log_{10}(A) \quad [C3.3.3]$$

where:

- *A is the area of incidence of wind pressure.*

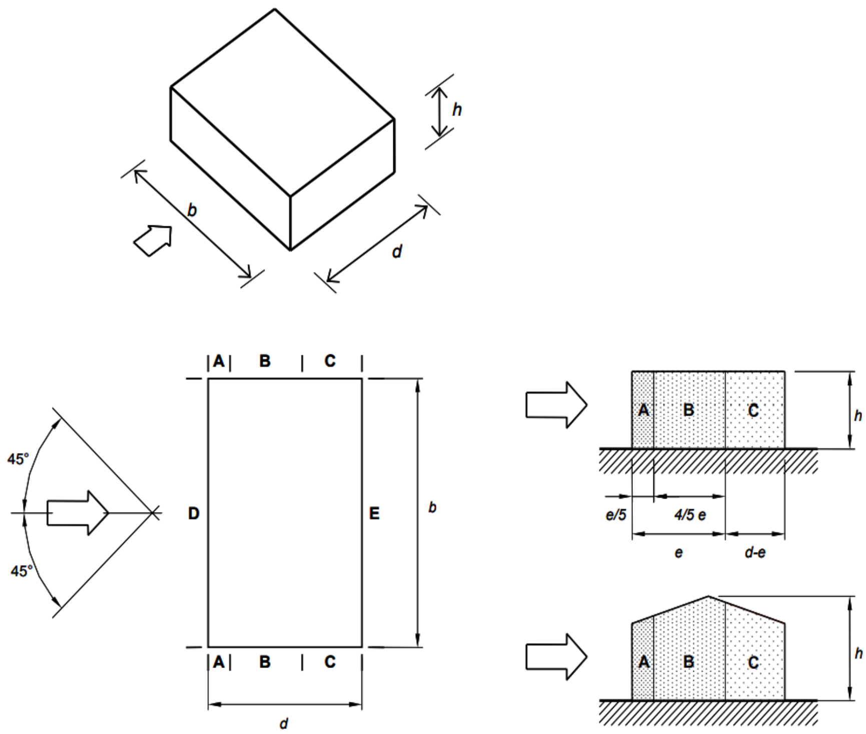


Figure 4.64_ Wind Geometry-Effect relation. Credits: NTC 2018

Considering that the building presents the following data:

- Width (b): 65.00 m
- Depth (d): 15.00 m
- Height (h): 25.00 m

and therefore, with an *h/d* ratio equal to 1.7, the values of the local pressure coefficients are assumed to be equal to:

Zona	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

Figure 4.65_Reference Table. Credits: NTC 2018

- $c_{pe,10}$ = -1.2
- $c_{pe,1}$ = -1.4

In summary, we have that:

q_r - kinetic reference pressure	391.63 N/m^2
c_e - exposure coefficient	2.00
c_d - dynamic coefficient	1
c_p - pressure coefficient	-1.4

We can then determine the value of the wind pressure as:

$$p = q_r \, c_e \, c_p \, c_d$$

$$p_w = 1093.93 \; N/m^2 = 1{,}09 \; kN/m^2$$

Moving to the **resistant actions**, they have been deduced based on the data collected from the technical data sheets of the producers, in particular reference was made - were present - to the items referring to the recommended load values.

The types of anchoring are obviously different depending on whether we are considering EASEE or TES panels.

EASEE panels

HALFEN - Body Anchor

- 3D adjustable brackets for wall panels made of natural stone or concrete.
- Stand-off distance of 30-330 mm.
- Can be used in horizontal and vertical joints.

Figure 4.66_ HALFEN DT Body (left), HALFEN BA Body (right).

HILTI – Steel Anchor

- High-performance metal anchor for static loads on cracked / non-cracked concrete (carbon steel).
- Material composition: Carbon steel, zinc plated.
- Head configuration: Externally threaded.
- Certifications/Test Results: ETA

HILTI

Recommended loads [a]

Anchor size			M6			M8			M10		
Eff. Anchorage depth	h_{ef}	[mm]	30	40	60	30	40	70	40	50	80
Tension N_{rec}	HSA, HSA-BW	[kN]	2,9	3,6	4,3	3,8	5,9	7,6	5,9	8,3	11,9
	HSA-R2, HSA-R		2,9	3,6	4,3	3,8	5,9	7,6	5,9	8,3	11,9
	HSA-F		2,9	3,6	4,3	3,8	5,9	7,6	5,9	8,3	11,9
Shear V_{rec}	HSA, HSA-BW	[kN]	2,9	*3,7*	*3,7*	3,8	*6,1*	*6,1*	*10,8*	*10,8*	*10,8*
	HSA-R2, HSA-R		2,9	*4,1*	*4,1*	3,8	*7,0*	*7,0*	*12,9*	*12,9*	*12,9*
	HSA-F		2,9	*3,7*	*3,7*	3,8	*6,1*	*6,1*	*10,8*	*10,8*	*10,8*
Anchor size			**M12**			**M16**			**M20**		
Eff. Anchorage depth	h_{ef}	[mm]	50	65	100	65	80	120	75	100	115
Tension N_{rec}	HSA, HSA-BW	[kN]	8,3	12,3	16,7	12,3	16,8	23,8	15,2	23,4	28,9
	HSA-R2, HSA-R		8,3	12,3	16,7	12,3	16,8	23,8	15,2	23,4	28,9
	HSA-F		8,3	12,3	16,7	12,3	16,8	23,8	15,2 [b]	23,4 [b]	28,9 [b]
Shear V_{rec}	HSA, HSA-BW	[kN]	16,6	*16,9*	*16,9*	*29,1*	*29,1*	*29,1*	30,4	*49,0*	*48,9*
	HSA-R2, HSA-R		16,6	*16,7*	*16,7*	*32,3*	*32,3*	*32,3*	30,4	*52,5*	*52,5*
	HSA-F		16,6	*16,9*	*16,9*	*29,1*	*29,1*	*29,1*	30,4 [b]	*39,2* [b]	*39,2* [b]

Table 4.8_ Technical sheet - HILTI anchor for EASEE panels.

TES panels

HILTI – Steel Anchor

- Plastic plug for high-performance frames (A2 stainless steel, countersunk head).
- Base materials: Concrete (aerated), Concrete (cracked), Concrete (uncracked), Masonry (concrete blocks filled with mortar), Masonry (hollow), Masonry (solid).
- Head configuration: Countersinking
- Certifications / Test Results: ETA, Fire

HRD | Ancorante universale

Carichi raccomandati [a)]

Dimensione ancorante			HRD 8	HRD 10		
			h_{nom} =50mm	h_{nom} =50mm	h_{nom} =70mm	h_{nom} =90mm
Calcestruzzo C 12/15 (fissaggio multiplo)	N_{rec}	[kN]	0,8	1,2	2,4	-
	V_{rec}	[kN]	3,9 / 3,7 [b)]	6,1 / 5,8 [b)] / 6,1 [c)]		-
Calcestruzzo C 16/20 – C 50/60 (fissaggio multiplo)	N_{rec}	[kN]	1,2	1,8	3,4	-
	V_{rec}	[kN]	3,9 / 3,7 [b)]	6,1 / 5,8 [b)] / 6,1 [c)]		-

Figure 4.67_ HILTI anchor for TES panels.

Therefore, considering each element under the **double action of Shear - Tensile**, we would have that:

$$\frac{F_{v,Sd}}{F_{v,Rd}} + \frac{F_{t,Sd}}{1.4 \cdot F_{t,Rd}} \leq 1.0$$

where is it:

- $F_{v,Sd}$: *design shear force* for each bolt at the ultimate limit state;
- $F_{t,Sd}$: *design tensile force* for each bolt at the ultimate limit state;
- $F_{v,Rd}$: *shear strength* per shear plane;
- $F_{t,Rd}$: *tensile strength*.

The **results obtained indicate the number of anchors necessary** so that the resultant of the resisting forces equals the resultant of the stressing actions and therefore, if rounded to the ceiling, constitute a significant estimate of the number of anchors required for each panel.

It should be noted that the fasteners calculated in this way are those that simultaneously resist shear and tensile stresses and therefore can be assimilated as:

- those at the base of the element for the *EASEE* type: the panel is in fact supported according to a support-hinge scheme and therefore it is unthinkable that the upper constraint is loaded by the weight of the panel placed below, which is instead attributed to the lower supports; for the wind force different reasoning was made, namely that all the anchors are actually involved in the response and therefore, focusing again on the row of supports placed in the lower part of the panel, they have an area of influence equal to half of the upper panel and half of the lower one which, assuming the approximately similar dimensions on elements placed on the same vertical, give about the dimensions of an entire panel.

- those at the base of the element of the *TES* type: although the type of "*screw*" anchoring to the coupling beam allows for both traction and shear stresses to be overcome in both directions (Z^+ and Z^-) - contrary to what has been said for the EASEE panels - the geometric configuration of the package indicates a specific approach from the support-support structural scheme. If we considered the single panel and the forces acting on it (weight and wind), each action would be equally divided between each screw; however, if we consider that each screw substantially serves as fastening for the connection elements between two panels one above the other, we see how each screw substantially takes loads of two adjacent panels and therefore must be sized on these values. Here too, for simplicity of calculation, it was assumed that the second panel had dimensions (m^2) comparable to the first and that therefore the actions of one also applied to the other (half a panel above and half a panel below make a whole panel).

Given the number, it was possible to define the **exact position** of each anchor also on the basis of the developed .dwg details - *ANNEX A-B-C*.

An **automatic script** was therefore developed that would allow **defining the position of each row and column of anchors**, using a triad of unique coordinates. Everything was done taking into account that the first always referred to the outer edge of the building (absolute height) while the following ones were indicated with respect to the previous element (relative height).

Below are some explanatory figures with the measures found.

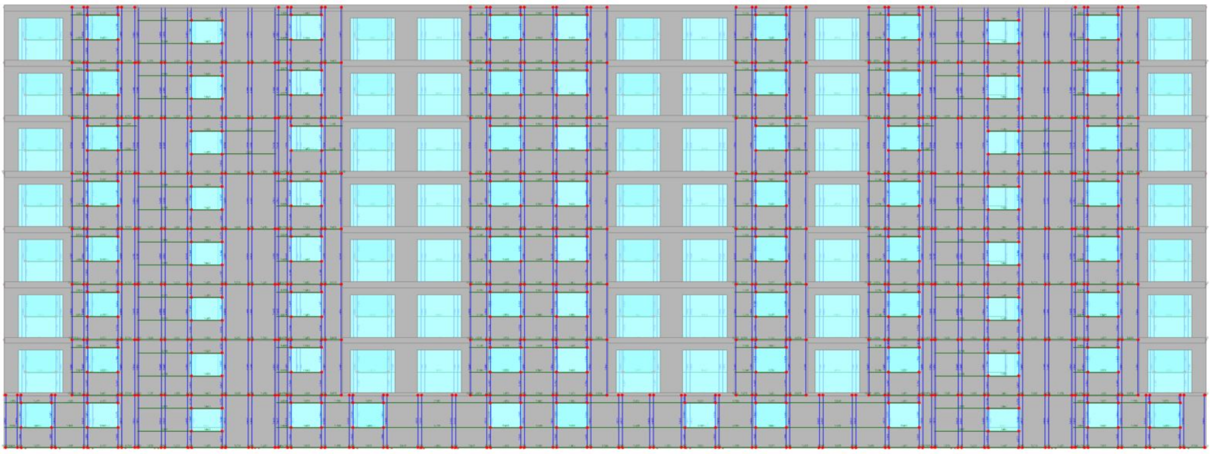


Figure 4.69_ Anchors Positioning - South Facade

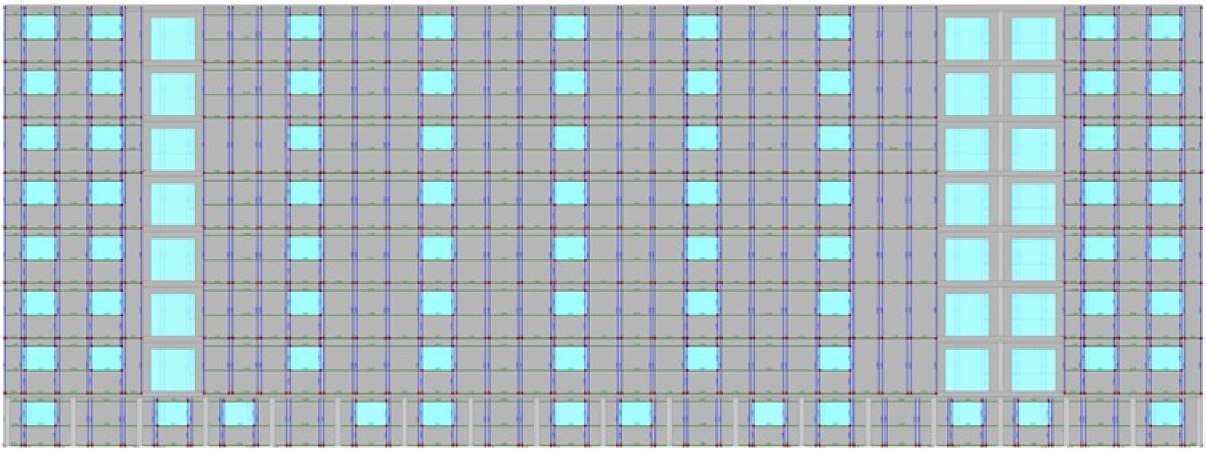


Figure 4.68_ Anchors Positioning - North Facade

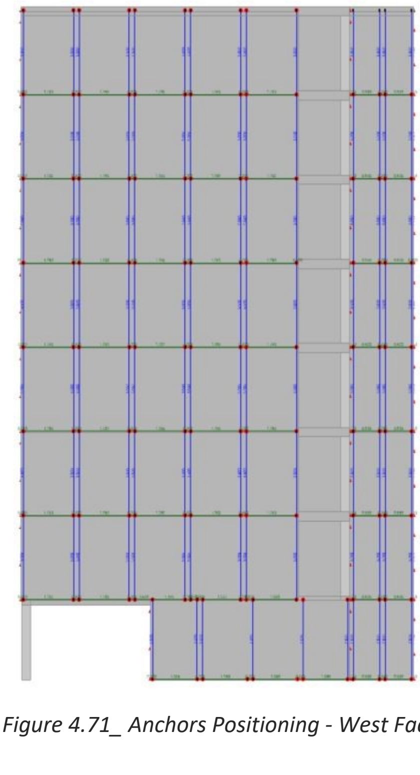


Figure 4.71_ Anchors Positioning - West Facade

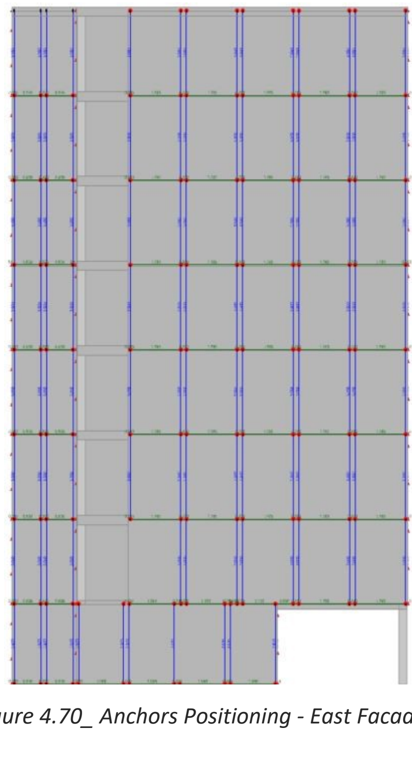


Figure 4.70_ Anchors Positioning - East Facade

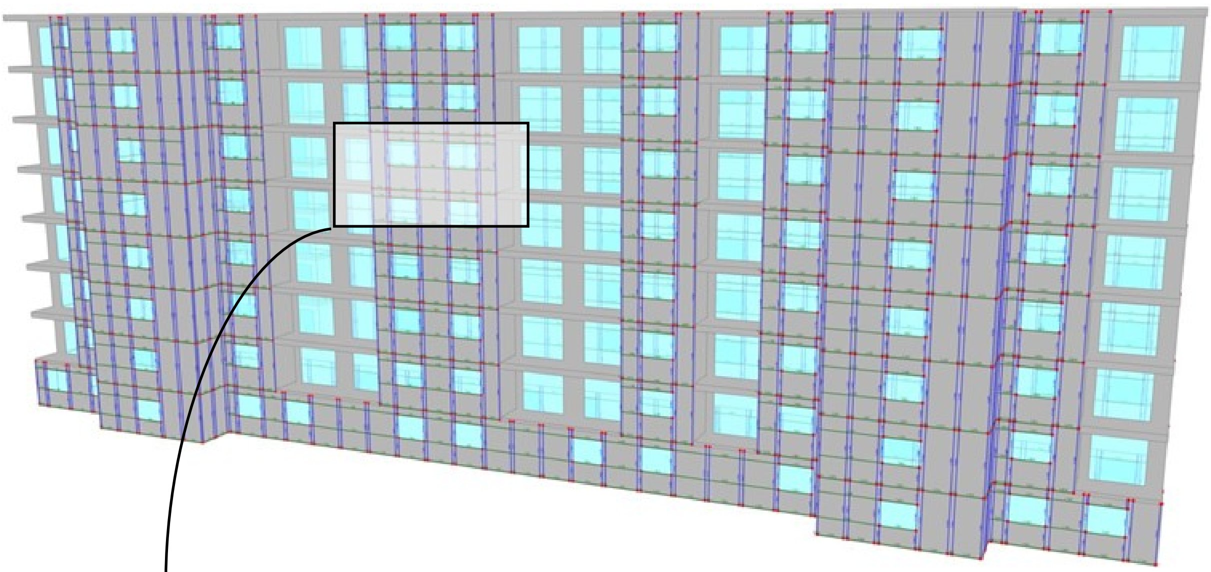


Figure 4.72_ Anchors disposition - SOUTH Perspective View A

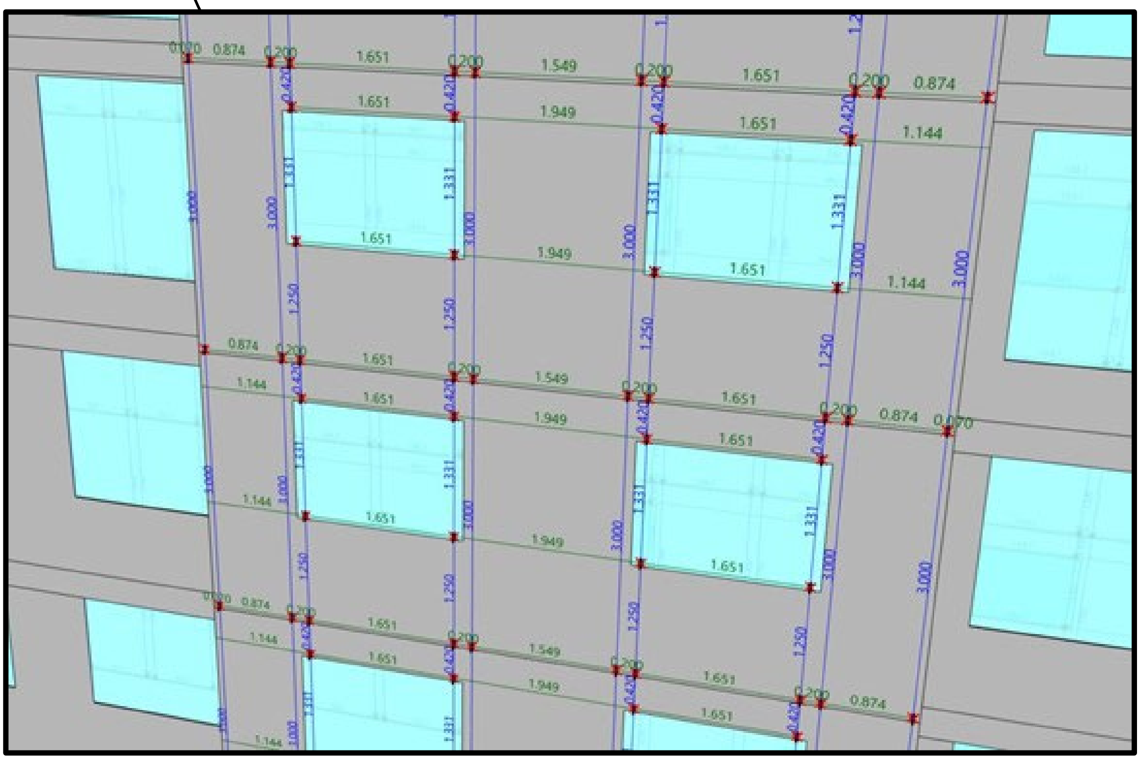


Figure 4.73_ Anchors disposition – SOUTH Perspective View A_Detail.00

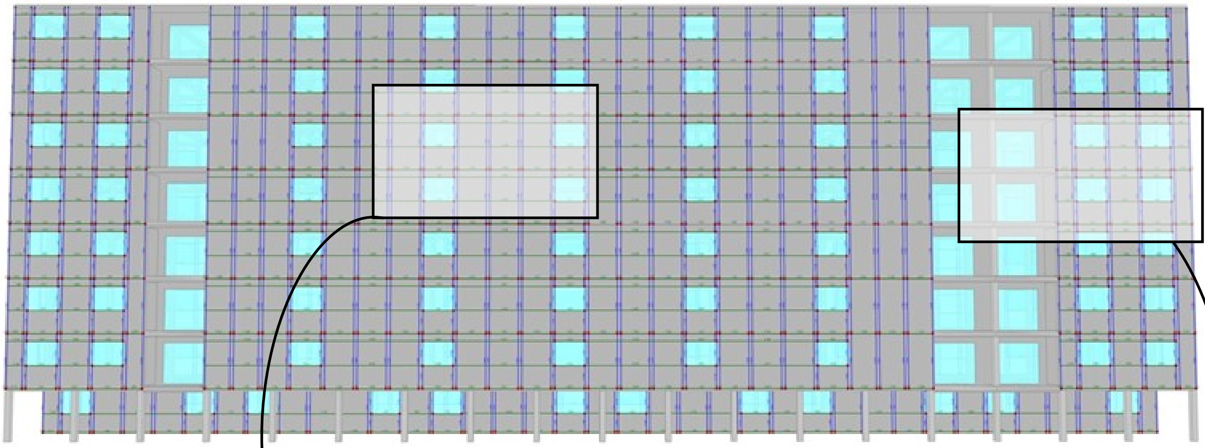


Figure 4.74_ Anchors disposition – NORTH Perspective View B

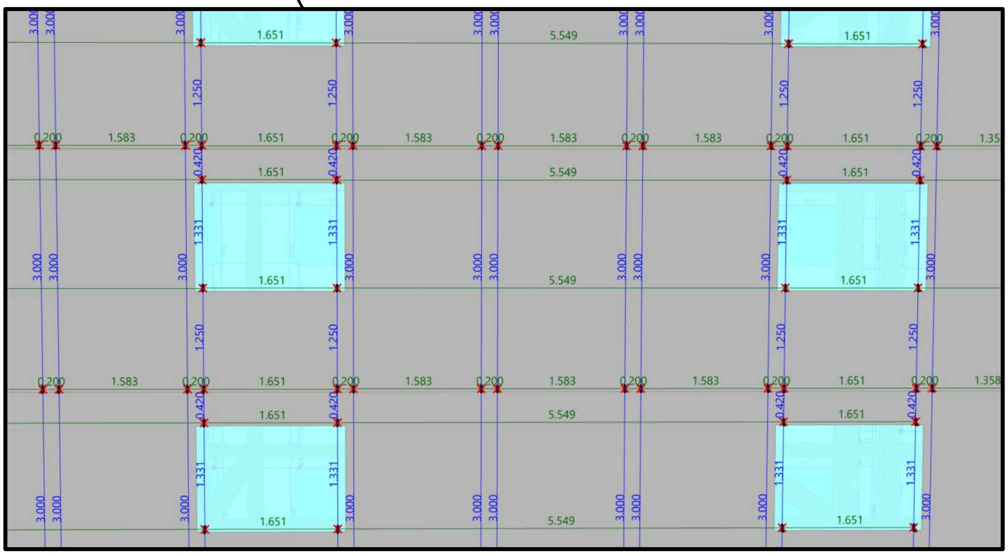


Figure 4.76_ Anchors disposition – NORTH Perspective View B_Detail.00

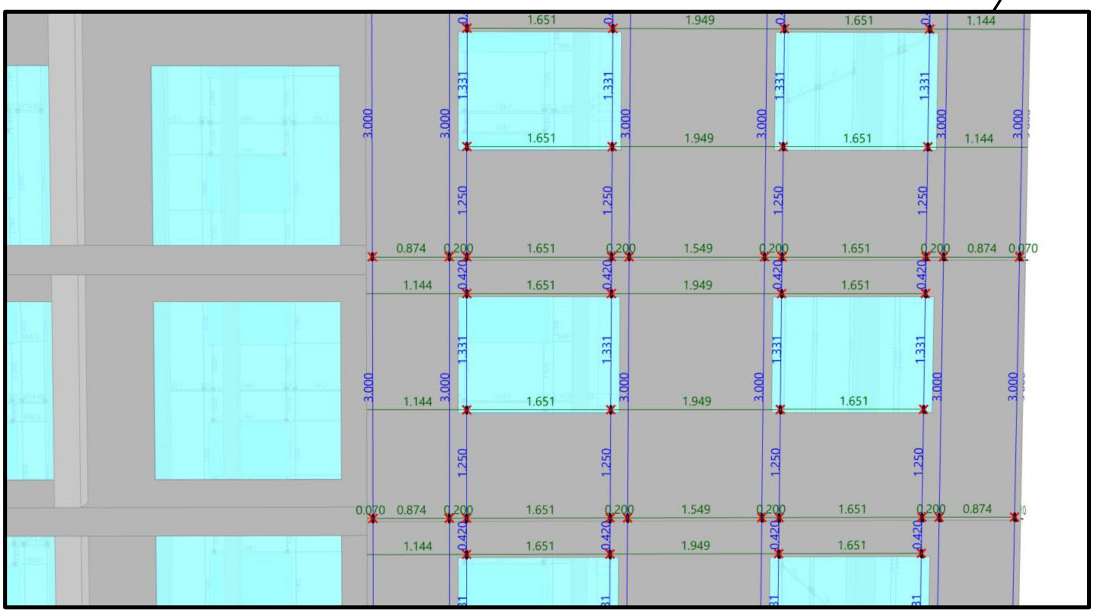


Figure 4.75_ Anchors disposition – NORTH Perspective View B_Detail.01

The last step of this study phase was to **export** each element **to Revit**. The passage is fundamental for the definition of the position of each one on the facade plane, a fundamental element for the management of clash/space/etc.

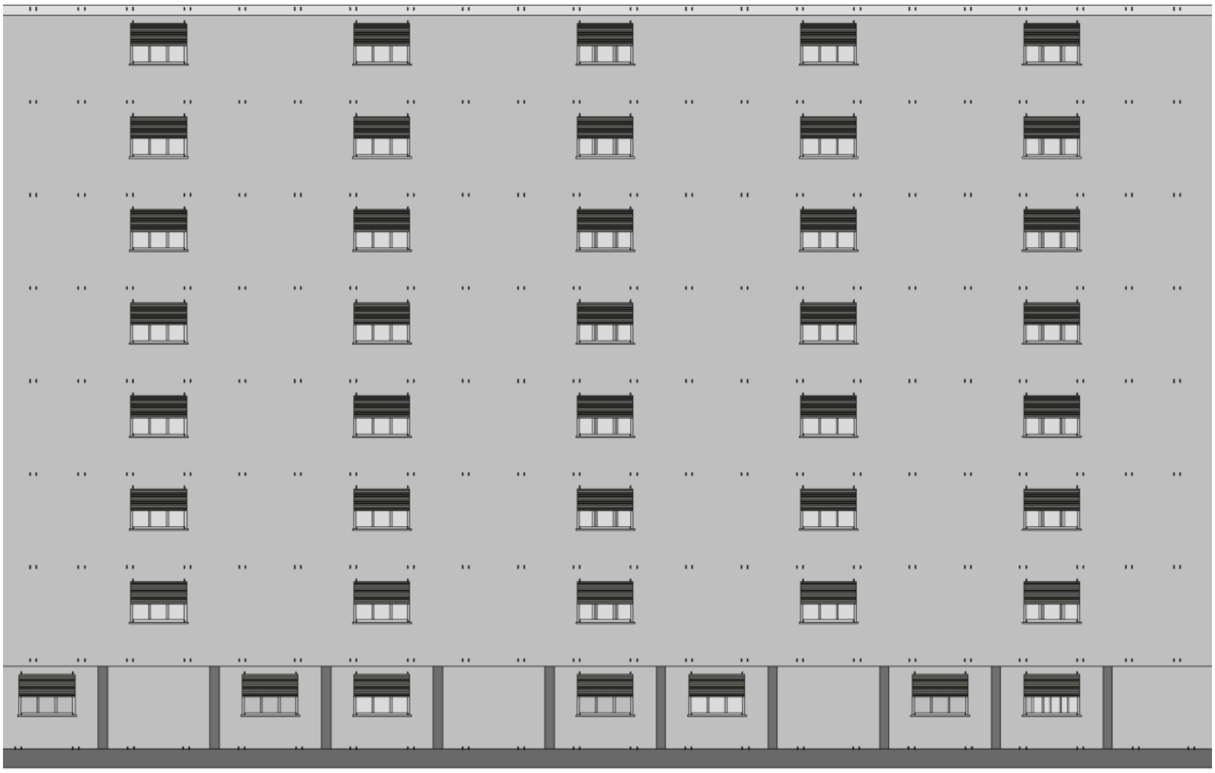


Figure 4.77_ Revit Anchors Export - North Facade (Portion)

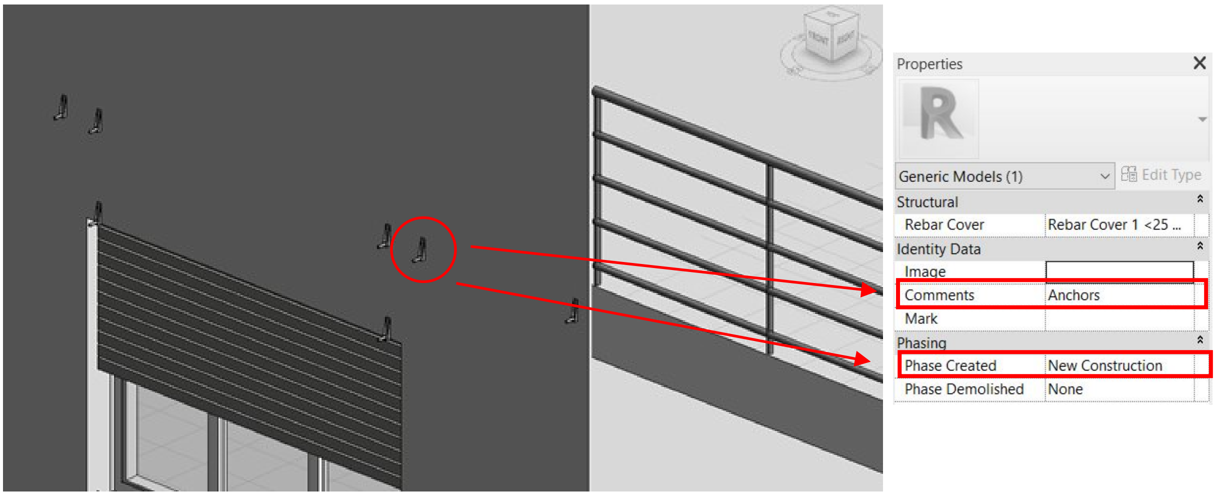


Figure 4.78_ Revit Anchors Export - Detailed view

Deformation

In the previous chapter, we proposed the necessary number of anchors as a reliable structural parameter to evaluate the performance of one solution compared to another. Although this is true, we think that the potential offered can go far beyond and could be intended as a real structural analysis of the panel itself, *in order to verify its real bearing capacity in relation to the assigned dimensions*.

Carrying out analysis to verify the range of the elements is certainly not new, however, we want to carry out these checks in a **parametric environment** or to be able to **connect other software to this** for the plot of the analysis outputs. In fact, we are interested in being able to record the results obtained by varying the input parameters in a Grasshopper / Excel environment and then put them in a single graph for comparison with others (energy, time, cost, etc.).

There is growing attention to **parametric design environments** (hence *Rhinoceros+Grasshoppper*) also by engineering figures belonging to the field of structures; if in a geometric modelling environment (shapes, volumes, etc.) this approach is already well established, the same cannot be said for **structural engineering**. However, the push this software is having is exponential and allow the development of different fields of design at different levels of depth, but with the advantage of remaining within the same design environment and therefore of making them communicate with each other. Research of aesthetics, thermal or lighting comfort analysis, structural capacity tests, etc. become possible within the same software with a continuous flow from the first to the last step. The first steps in this direction are moving. In fact, both plug-ins supported by the software houses themselves (*Dlubal Software*) or by people who are in any case close to these structural engineering environments have been released; a **very short list** can be the following:

- *RFEM | 3D STRUCTURAL ANALYSIS SOFTWARE*

  Developed by Dlubal Software

  https://www.food4rhino.com/resource/rfem-3d-structural-analysis-software

  Can import and export models from and to Rhino and there is a Menu in Grasshopper with components to Launch the export to RFEM, create surfaces, create members, etc.
- *Karamba3D*

  Developed by Clemens Preisinger in cooperation with Bollinger und Grohmann ZTGmbH in Vienna https://www.karamba3d.com/

  Karamba3D is an interactive, parametric finite element program; it lets you analyze the response of 3-dimensional beam and shell structures under arbitrary loads.
- *PARAMETRIC FEM TOOLBOX*

  Developed by Diego Apellániz in cooperation with Bollinger und Grohmann ZTGmbH in Vienna https://github.com/diego-apellaniz/Parametric-FEM-Toolbox

  This Plug-In enables interoperability between the finite element software RFEM (Structural Analysis) and Grasshopper through the RFCOM API. It´s required to have installed the program Dlubal RFEM with active RFEM and RFCOM licenses in order to use this plugin. It allows you to import data from

Grasshopper to RFEM (Model Data, Loads, Load Cases, Load Combinations, etc.), import Data from RFEM into Grasshopper, run structural calculations from Grasshopper, visualize RFEM Models in Rhino.

- *Panda Plugin*
  Developed by Drilon Shabani
  https://www.youtube.com/watch?v=-m2PKXlWzgk&t=3s&ab_channel=DrilonShabani
  It allows you to export geometries, constraints and materials directly from Grasshopper to Midas CIVIL, without the aid of intermediate steps.
- ALPACA4D
  Developed by Marco Pellegrino and Domenico Gaudioso
  https://www.food4rhino.com/app/alpaca4d
  Alpaca4d is a Grasshopper plugin that has been developed on top of OpenSees; it lets you analyze beam, shell and brick elements through Static, Modal and Ground Motion Analysis.

DEFORMATION – KARAMBA 3D

To explore the possibilities of applying this new approach in our case, we decided to test the **TES panels in terms of deformation in Karamba3D** to open new possibilities for comparison between different types.

The software was chosen because it has a good bibliography and sample video tutorials, as well as being developed in association with the company *Bollinger und Grohmann of which Eng. Tommaso Pagnacco is Milan Branch Manager*. It, therefore, seemed a good choice to be able to count on it.

The main steps that the modelling followed were based on the real structure that these panels have: a frame of wooden elements made of mullions and transoms (in the upper and lower part), joined by two panels of Oriented Strain Board (OSB) on each side to close the package and further stiffen the system.

The script was therefore developed following what has just been said, paying particular attention to leaving freedom of choice to the parameters that describe:

- the thickness of the OSB slabs;
- the dimensions of the wooden profiles;
- the spacing of the mullions;
- the spacing of the OSB metal connectors.
- the number of anchors to the building structure.

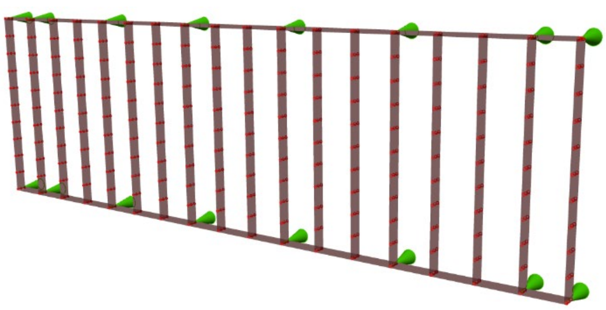


Figure 4.79_ Editable parameters of the TES structure

Here we see at work all those possibilities we mentioned earlier, the management of the parameters connected with the structural verification of complex elements allows us to have a response quickly and without major efforts of global remodelling.

The acting loads considered are those of Dead Load and Wind Load (-), whose values were taken from the calculations made in the previous Chapter ("*Anchors*").

The results were obtained assuming:

- Mullions: 12x6 cm section and 0.60 m span;
- Transom: 12x5 cm section;
- OSB/4 plates: thickness 0.023 cm per side;
- Screws: 6 mm diameter and 0.30 m spacing.

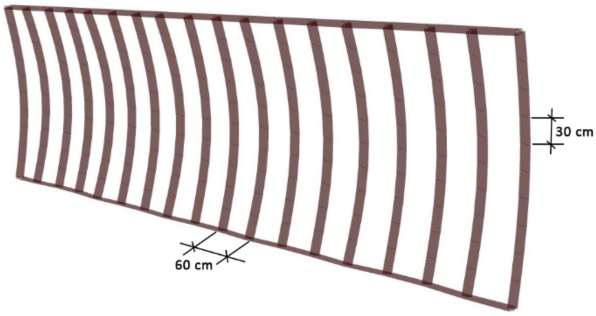


Figure 4.80_ TES panel deformed (deformation scale rate: x100).

With these assumptions, the system has a maximum deformation value equal to **3.2 mm**, below the limit threshold set at l/300 which means **10 mm** for a height of 3 m.

As proof, it was hypothesized to calculate the deformation of a wooden upright in a condition of simple support with a uniformly distributed load; the deformation, in this case, is calculated with the well-known formula:

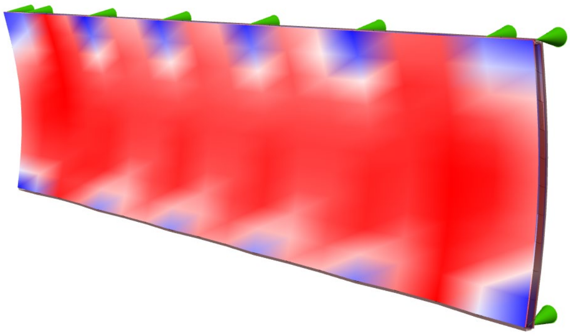


Figure 4.81_ TES panel - OSB plates utilization.

$$d_{max} = \frac{5}{384} \cdot \frac{ql^4}{EI} = \frac{5}{384} \cdot \frac{ql^4}{EI} = \mathbf{4.6\ mm}$$

Obviously, there is an inconsistency in the results with the previous case (and it is normal to be so), because the hypothesis of simple support is too limiting. However, what has been done allows us to see how the presence of a timber frame combined with an OSB plate on each side contributes to the improvement of overall performance, reducing the maximum deformation by about 30.4 %.

The same approach has been taken for the TES panels with the holes due to the windows.

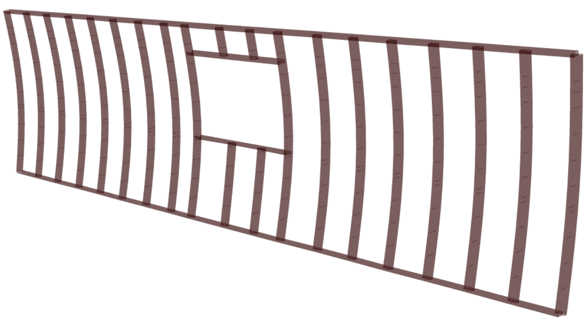


Figure 4.82_ TES panel + window hole (deformation scale rate: x20).

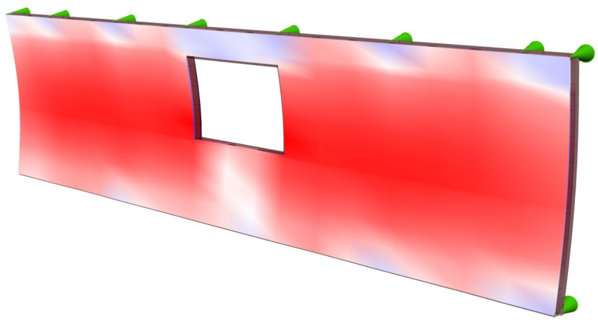


Figure 4.83_ TES panel + window hole - OSB plates utilization.

DEFORMATION – DLUBAL RFEM

However, we have tried to take a further step, that is to probe the actual **export possibilities** of the geometries on a **Dlubal RFEM** finite element structural calculation modelling software. Although it was not our interest to actually carry out a structural calculation verification of the panel capacity, it is important to understand to what extent interoperability is guaranteed and the possibility of delegating the ability to carry out more in-depth analyzes to other software. The plugin we used is Diego Apellániz's Parametric FEM Toolbox, also made in collaboration with *Bollinger + Grohmann*. The potential of the program allows you to import data from Grasshopper into RFEM (geometries, loads, etc.) and vice versa, even being able to run the analyzes through Grasshopper and read here the results of the data obtained.

We then tested the real potential of the software by drawing on the modelling carried out on Karamba3D in terms of model, materials, sections, loads and constraints. Although the components had different names, the steps of the process were the same and this greatly speeded up the various phases. In the end, by properly connecting all the required items, it is possible to export the model directly to Dlubal RFEM as it was modelled on Grasshopper.

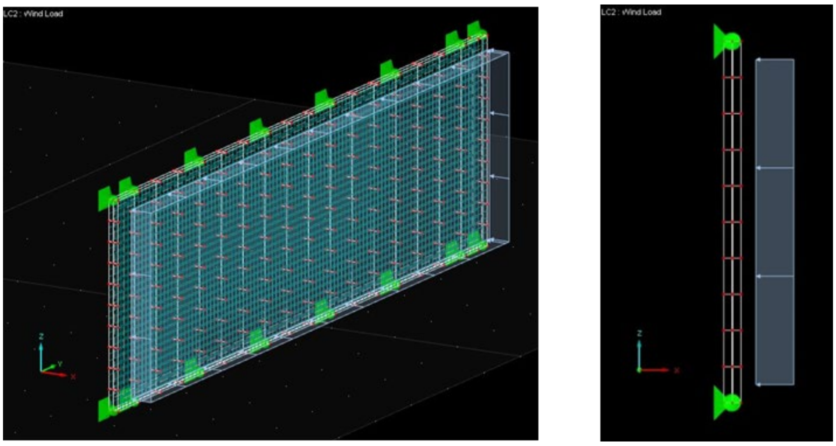


Figure 4.84_ TES panel exported to Dlubal RFEM.

The advantages are enormous, we can in fact take advantages of the certainly superior calculation capabilities of RFEM together with the ease of modelling of a visual programming software like Grasshopper. In fact, it is possible to (for example) **change the step of all the connectors at any time**, replot the model on RFEM and from there relaunch the analysis whose results are reimported on Grasshopper through a specific command, ready to be inserted in the decision support system to be analyzed with the other parameters.

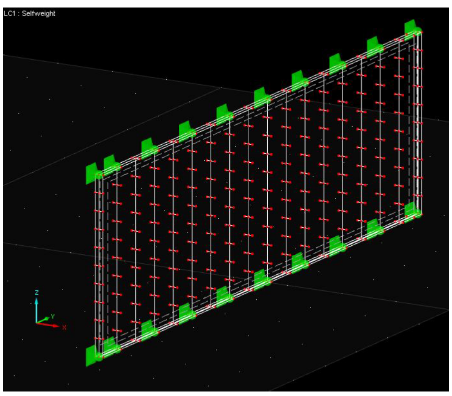


Figure 4.86_ TES panel - 40 cm mullions spacing, 10 wall anchors, 12 screws per mullion.

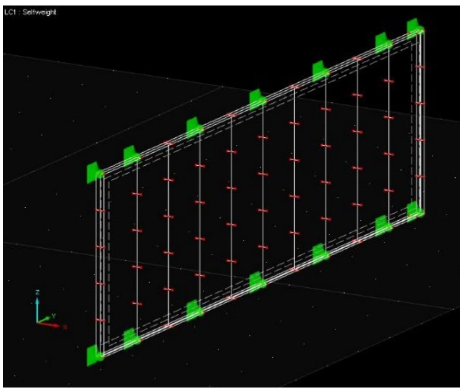


Figure 4.85_ TES panel - 80 cm mullions spacing, 7 wall anchors, 6 screws per mullion.

Energy 2.0 (H’t)

CHAPTER’S SUMMARY:

After defining the geometric dimensions of the panels and verifying their structural feasibility, we proceed with a more refined calculation of the energy performance of the building that takes into account the dimensions of the dispersing areas and thermal bridges. The possibility to choose between several paneling configurations changes the value of the chosen parameter, so as to make the choice of the size of the individual panels fundamental.

In order to have a more precise idea of how the thermal quality of the building envelope as a whole is, a more in-depth energy analysis was carried out thanks to a new parameter introduced by the *D.M.*: the calculation of the global average heat exchange coefficient. H't.

The global average coefficient of heat exchange by transmission per unit of dispersing surface (H't) *characterizes the performance of the envelope in winter conditions*.

H’t is expressed in W/(m^2K) and is obtained as:

$$H't = \frac{H_{tr,adj}}{\Sigma_K \times A_K}$$

In which:

- $H_{tr,adj}$ is the global coefficient of heat exchange by the transmission of the envelope calculated with the UNI/TS 11300-1[74] (W/K);
- A_K is the surface of the k-th component (opaque or transparent) of the envelope (m^2).

According to the UNI/TS 11300-1 the parameter $H_{tr,adj}$ is calculated using the formula:

$$H_{tr,adj} = H_D + H_g + H_U + H_A$$

In which:

- H_D is the direct heat exchange coefficient for transmission to the external environment, expressed in (W/K);
- H_g is the stationary heat exchange coefficient for transmission to the ground, expressed in W/K);
- H_U is the heat exchange coefficient for transmission through non-conditioned environments, expressed in (W/K);
- H_A is the heat exchange coefficient for transmission to other air-conditioned zones at different temperatures, expressed in (W/K); generally, only the exchange of thermal energy to air-conditioned areas of other buildings is considered and not to the thermal areas of the building itself (calculation with non-coupled thermal zones).

The calculation of the heat exchange coefficients for transmission H_D, H_g, H_U, H_A is carried out according to the UNI EN 13789:2008 [75] and UNI EN ISO 13370 [76].

The value of $H't$ must be lower than the maximum admissible value shown in the following table, depending on the climatic zone and the S/V ratio.

Numero Riga	RAPPORTO DI FORMA (S/V)	Zona climatica				
		A e B	C	D	E	F
1	S/V ≥ 0,7	0,58	0,55	0,53	0,50	0,48
2	0,7 > S/V ≥ 0,4	0,63	0,60	0,58	0,55	0,53
3	0,4 > S/V	0,80	0,80	0,80	0,75	0,70
Numero Riga	**TIPOLOGIA DI INTERVENTO**	**Zona climatica**				
		A e B	C	D	E	F
4	Ampliamenti e Ristrutturazioni importanti di secondo livello per tutte le tipologie edilizie	0,73	0,70	0,68	0,65	0,62

Table 4.9_ Limit values of H't.

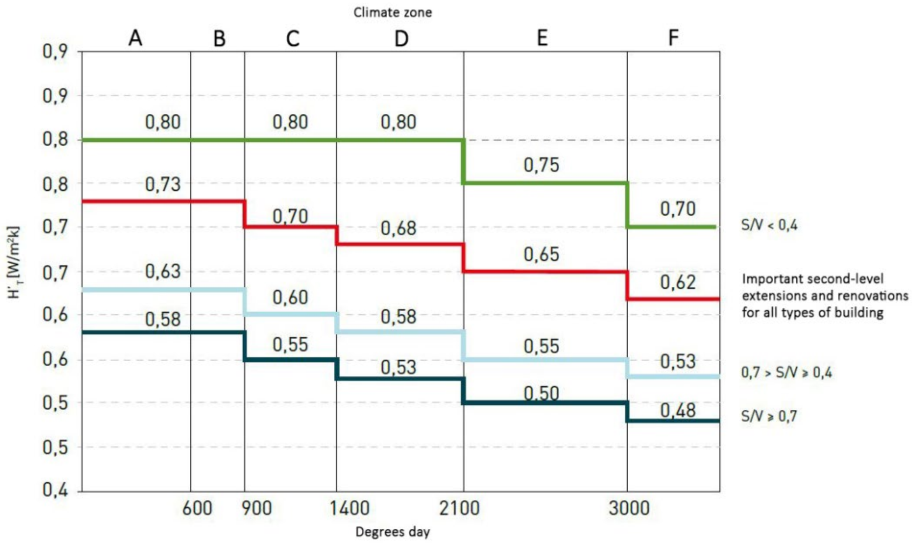


Figure 4.87_ Limit values of H't. Credits: Rockwool (modified)

The values in the table above, refer to new buildings and major I and II level renovations:

- It is level I restructuring if $\frac{S_{ren}}{S_{TOT}} \geq 0.50$;
- It is level II restructuring if $0.25 \leq \frac{S_{ren}}{S_{TOT}} < 0.50$;

If the renovation includes less than 25% of the useful surface, it is a simple energy requalification.

For a simplified and faster analysis, it was decided to neglect the H_U and H_A coefficients, assuming that the whole building has air-conditioned rooms and that there is no heat exchange with the rooms of other buildings.

So, the calculation of H't can be summarized as follows:

$$H't = \frac{H_D + H_g}{\Sigma_K \times A_K}$$

Calculation of H_D

The direct heat exchange coefficient for transmission to the external environment H_D is calculated as:

$$H_D = \Sigma_i A_i U_i + \Sigma_k l_k \psi_k + \Sigma_k X_k$$

where:

- A_i is the area of the i-th element of the building envelope (m^2);
- U_i is the thermal transmittance of the i-th element of the building envelope (W/m^{2}K);

- l_k is the length of the k-th linear thermal bridge (m);
- ψ_k is the linear thermal transmittance of the k-th thermal bridge (W/m);
- X_k is the punctual thermal transmittance of the j-th punctual thermal bridge (W/m).

In our case the punctual thermal transmittance X_k has been neglected. The calculation of the other parameters is not trivial and requires a good discretization of the geometry of the building envelope, to be able to parametrically identify the different lengths of the linear thermal bridges l_k which will then be multiplied with the respective linear transmittance coefficients ψ_k.

As a first step, therefore, we developed a section of the script that would give us the areas (A_i) of every single element on the facade of the building envelope. 7 types have been identified:

N°.	Elements	Notes
1	Roof	Given the high dispersion on the roof, this will be upgraded with the addition of an insulator that decreases the thermal transmittance of the surface.
2	Perimetral Walls	The Perimetral Walls are the surfaces on which our attention is mainly focused: here the 3 configurations under study (ETICS, EASEE and TES) will be tested.
3	Windows	Transparent surfaces are the most sensitive areas in buildings: no intervention on them was planned in our study.
4	ETICS | Vertical	Less exposed vertical opaque surfaces (such as loggias) are difficult to panel, which is why they will always be redeveloped with the ETICS system.
5	ETICS | Horizontal	Horizontal opaque surfaces (such as overhangs) are difficult to panel, which is why they will always be redeveloped with the ETICS system.
6	French Doors	Transparent surfaces are the most sensitive areas in buildings: no intervention on them was planned in our study.
7	Balconies	-

To have greater control of the dispersion of the envelope, we are able to extrapolate the results according to the orientation of the facade (N, E, S, W).

At this point, a section has been developed in which **it is possible to choose the configuration to be applied to every single element** shown in the table above. Depending on the choice made, the script can automatically read the corresponding thermal transmittance value (U_i) thanks to the real-time connection with the information contained in the reference Excel file (in which all the studied configurations are present).

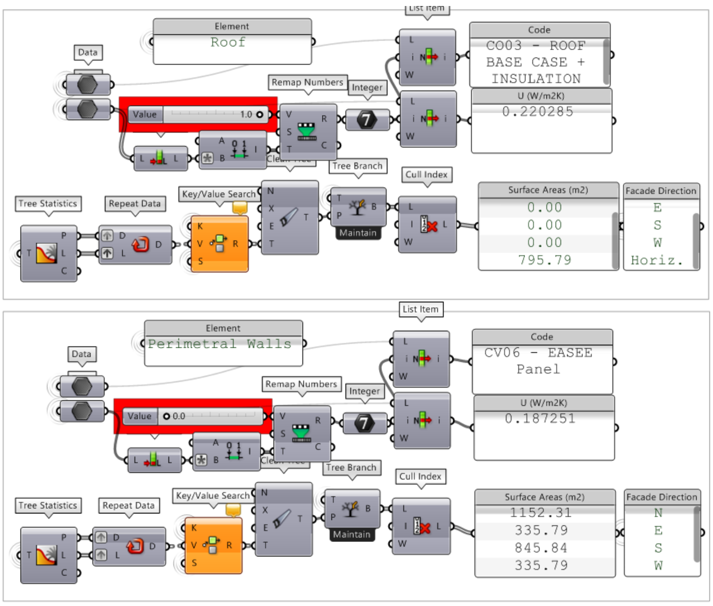


Figure 4.88_ Technologies choice for roof and perimetral walls.

We are able to obtain:

- The total area of each side (m^2);
- Total A*U of each side (W/K);
- $U_{average}$ of each side (W/m^2K);
- Total area of each element (m^2);
- Total A*U of each element (W/K).

All the **information are automatically exported to the reference Excel file** so that the data obtained are accessible to anyone. The tables below show the configurations chosen for the redevelopment of our case study. The transparent surfaces and the balconies have not been renovated: for the purposes of our study, the balconies are identified as "CO01 ROOF-BASE CASE" as this configuration can be considered a good approximation of a generic floor.

						Surface Areas [m²]				
N°	Elements	Code NORTH	Code EAST	Code SOUTH	Code WEST	N	E	S	W	Horiz.
1	Roof	CO03 - ROOF BASE CASE + INSULATION	CO03 - ROOF BASE CASE + INSULATION	CO03 - ROOF BASE CASE + INSULATION	CO03 - ROOF BASE CASE + INSULATION	0	0	0	0	795.79
2	Perimetral Walls	CV06 - EASEE Panel	CV06 - EASEE Panel	CV06 - EASEE Panel	CV06 - EASEE Panel	1152.31	335.79	845.84	335.79	0
3	Windows	WINDOW	WINDOW	WINDOW	WINDOW	183.33	0	183.31	0	0
4	ETICS | Vertical	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	73.97	203.72	183.31	203.72	0
5	ETICS | Horizontal	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	280.68	0	0	0	0
6	French Doors	WINDOW	WINDOW	WINDOW	WINDOW	115.92	0	270.48	0	0
7	Balconies	CO01 - ROOF BASE CASE	CO01 - ROOF BASE CASE	CO01 - ROOF BASE CASE	CO01 - ROOF BASE CASE	134.68	0	325.5	0	0
					Tot. Length for each side [m]	1940.89	539.51	1808.44	539.51	795.79

						U_N [W/m²K]	U_E [W/m²K]	U_S [W/m²K]	U_W [W/m²K]	$U_{horizontal}$ [W/m²K]	A*U [W/K]				
N°	Elements	Code NORTH	Code EAST	Code SOUTH	Code WEST	N	E	S	W	Horiz.	N	E	S	W	Horiz.
1	Roof	CO03 - ROOF BASE CASE + INSULATION	CO03 - ROOF BASE CASE + INSULATION	CO03 - ROOF BASE CASE + INSULATION	CO03 - ROOF BASE CASE + INSULATION					0.22	0.00	0.00	0.00	0.00	175.30
2	Perimetral Walls	CV06 - EASEE Panel	CV06 - EASEE Panel	CV06 - EASEE Panel	CV06 - EASEE Panel	0.19	0.19	0.19	0.19		215.77	62.88	158.38	62.88	0.00
3	Windows	WINDOW	WINDOW	WINDOW	WINDOW	1.52	1.52	1.52	1.52		278.67	0.00	278.64	0.00	0.00
4	ETICS | Vertical	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.21	0.21	0.21	0.21		15.44	42.53	38.27	42.53	0.00
5	ETICS | Horizontal	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.21	0.21	0.21	0.21		58.60	0.00	0.00	0.00	0.00
6	French Doors	WINDOW	WINDOW	WINDOW	WINDOW	1.52	1.52	1.52	1.52		176.20	0.00	411.14	0.00	0.00
7	Balconies	CO01 - ROOF BASE CASE	CO01 - ROOF BASE CASE	CO01 - ROOF BASE CASE	CO01 - ROOF BASE CASE	1.54	1.54	1.54	1.54		208.00	0.00	502.70	0.00	0.00
										Tot. A*U for each side [W/K]	952.68	105.41	1389.14	105.41	175.30
										$U_{average}$ for each side [W/m²K]	0.49	0.20	0.77	0.20	0.22

Then, we focused on obtaining the lengths of the linear thermal bridges (l_k). 24 different types have been identified:

N°	Elements	N°	Elements
1	Roof|Staircase|H	13	Middle L.T.B.|Ext. Overhang|H
2	Roof|Building|H	14	Middle L.T.B.|Int. Overhang|H
3	Middle L.T.B.|Staircase|V	15	Middle L.T.B.|Balconies|H
4	Corner Staircase/Building |V	16	Windows|Staircase UP|H
5	Corner Staircase |V	17	Windows|Staircase DOWN|H
6	Middle L.T.B.|Building|V	18	Windows|Building UP|H
7	Corner ETICS/Panel |V	19	Windows|Building DOWN|H
8	Corner Panel/Panel |V	20	Basement|Staircase|H
9	Windows|Staircase|V	21	Basement|Building|H
10	Windows|Building|V	22	French Door DOWN|H
11	Middle L.T.B.|Staircase|H	23	French Door UP|H
12	Middle L.T.B.|Building|H	24	French Door|V

The following figure shows the different types of thermal bridge lengths corresponding to the surfaces on which we panelised.

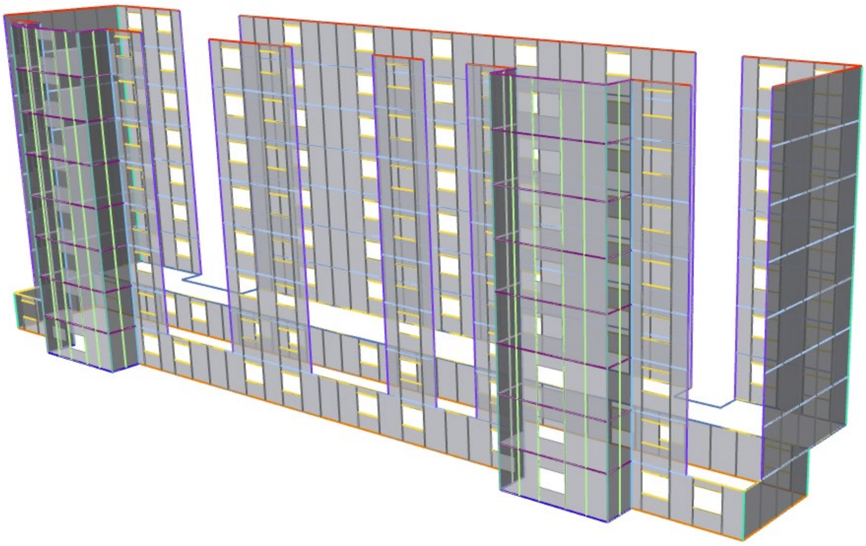


Figure 4.89_ Colours referred to the different linear thermal bridges.

At this point, we have made an in-depth study of the nodes subject to linear thermal bridges so as to be able to calculate the linear thermal transmittance of the thermal bridge (ψ_k). To do this, the THERM component contained in Honeybee (a Grasshopper plug-in) was used which allowed us to analyse many nodes in a parametric way, allowing easier adaptation to changes.

To further speed up the tool, we may think in the future to refer to schedules to evaluate the entity of the linear thermal transmittances of thermal bridges: this would make the values obtained less precise, but for the purpose of an analysis that is to be carried out during Early Design Stage, it would speed up the study a lot.

The linear thermal transmittance of the thermal bridge (ψ_k) is obtained through the finite element calculation (UNI EN ISO 10211-2[77]).

The boundary conditions that have been defined are still the following:

Boundaries Conditions			
T_{INT} [°C]	20.00	UR_i [%]	50
T_{EST} [°C]	-5.00	UR_e [%]	85
h_i [W/m^2*K]	8.00	R_i [m^2*K/W]	0.13
h_e [W/m^2*K]	25.00	R_e [m^2*K/W]	0.04

Figure 4.90_ Boundaries conditions.

The heat flow rate per metre length ϕ_{2D}, of the linear thermal bridge from the external environment, is given by the formula:

$$\phi_{2D} = L_{2D} \times (T_{IN} - T_E) \quad \left[\frac{W}{m}\right]$$

Where L_{2D} is the thermal coupling coefficient obtained from a 2-D calculation of the component separating the two environments being considered.

Then, L_{2D} is equal to:

$$L_{2D} = \frac{\phi_{2D}}{\Delta T} \quad \left[\frac{W}{m \times K}\right]$$

The linear thermal transmittance ψ_e (external dimension) is given by:

$$\psi_e = L_{2D} - \sum_{j=1}^{N_j} U_{j-1D} \times l_j \quad \left[\frac{W}{m \times K}\right]$$

Where:

- U_j is the thermal transmittance of the 1-D component j separating the two environments being considered;
- l_j is the length within the 2-D geometrical model over which the value U_j applies.

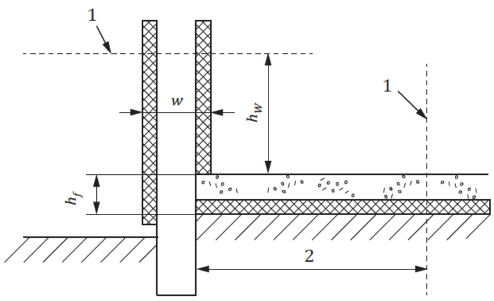
LINEAR THERMAL TRANSMITTANCE FOR WALL/FLOOR JUNCTIONS

When the calculation involves heat transfer via the ground (foundations, ground floors, basements), the cut-off planes in the ground shall be as indicated in the following table:

Direction	Distance to central element	
	Purpose of the calculation	
	Surface temperatures only	Heat flow and surface temperatures[a]
Horizontal distance to vertical plane, inside the building	at least three times wall thickness	0,5 × floor dimension[b]
Horizontal distance to vertical plane, outside the building	at least three times wall thickness	2,5 × floor width[c,d]
Vertical distance to horizontal plane below ground level	at least 3 m	2,5 × floor width[c]
Vertical distance to horizontal plane below floor level (applies only if the level of the floor under consideration is more than 2 m below the ground level)	at least 1 m	2,5 × floor width[c]

Figure 4.91_ Location of cut-off planes in the ground.

After modelled the full detail of the node, including 4 m of the floor inside the building, a section of the wall to height h_w and extended the model outside the building and below ground level for 2.5 times the floor width, we calculate the linear thermal transmittance following the "option A" of the EN ISO 10211. "Option A" gives the formula for calculating ψ_g when "**inside floor level is equal or higher than outside level**".



Key
1 adiabatic boundary
2 0,5 × *B* or 4 m
h_f height of the top of the floor slab above ground level
h_W minimum distance from junction to cut-off plane (see 7.2.3)
w width of the wall above ground

NOTE The dimensions of the model extend to 0,5 × *B* inside the building and to 2,5 × *B* outside the building and below ground.

Figure 4.92_ Model for calculation of linear thermal transmittance of wall/floor junction.

ψ_g is calculated by using the external dimension:

$$\psi_g = L_{2D} - (h_w + h_f) \times U_w - (0.5 \times B + w) \times U_g$$

Where:

- U_w is the thermal transmittance of the wall above the ground;
- h_w is the minimum distance from junction to cut-off plane;
- h_f is the height of the top of the floor slab above ground level;
- w is the width of the wall above the ground.

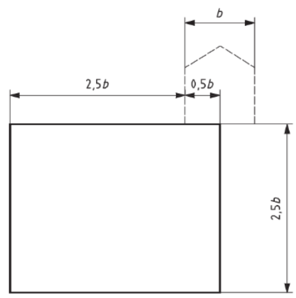


Figure 4.93_ Cut-off planes for 2-D geometrical model which includes the ground.

The finite element method calculates the overall heat flow of the section and subtracts the product between $\mathbf{U_{j-1D}}$ and the length of the section (flow through the wall without thermal bridge).

We report below all the nodes analysed in THERM.

ETICS

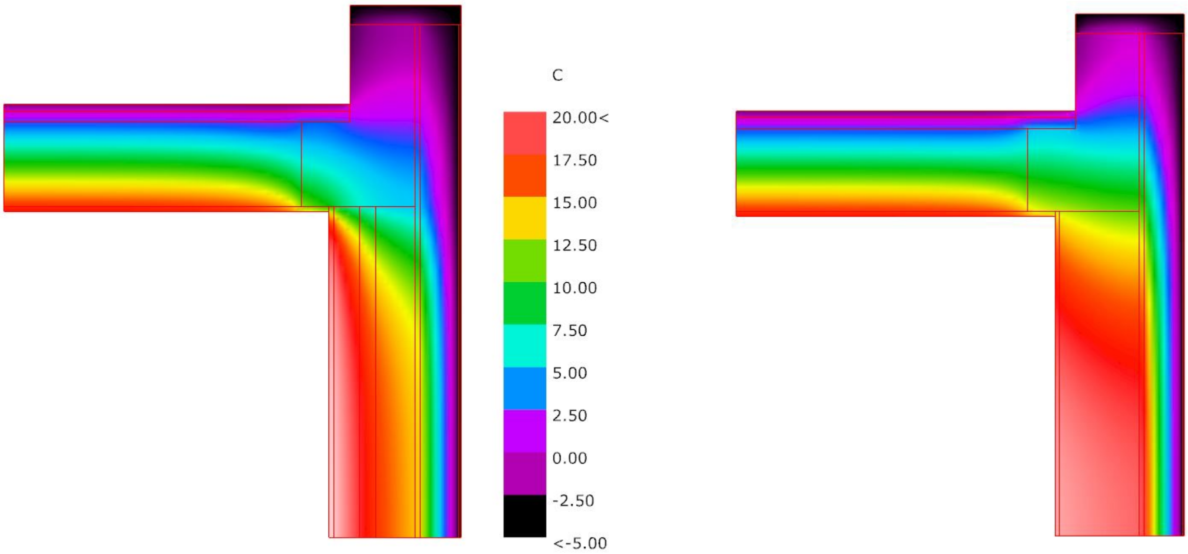


Figure 4.94_ Roof|Building|H (left), Roof|Staircase|H (right) – with NO insulated roof.

We have studied the roof/wall node with only the renewal of the wall, in order to leave the possibility of choosing whether to intervene on the roof or not. The node shows condensation problems, therefore intervention in the roof is necessary (node analysed in the following pages).

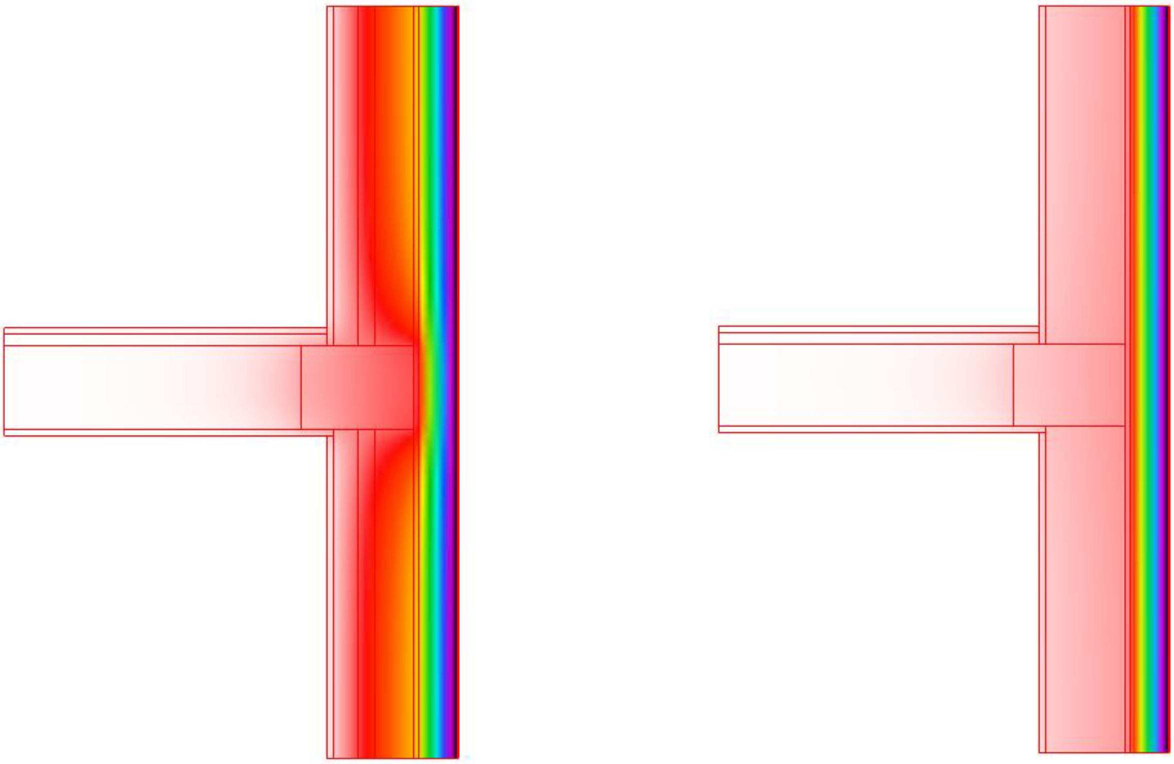


Figure 4.95_ Middle L.T.B.|Building|H (left), Middle L.T.B.|Staircase|H (right).

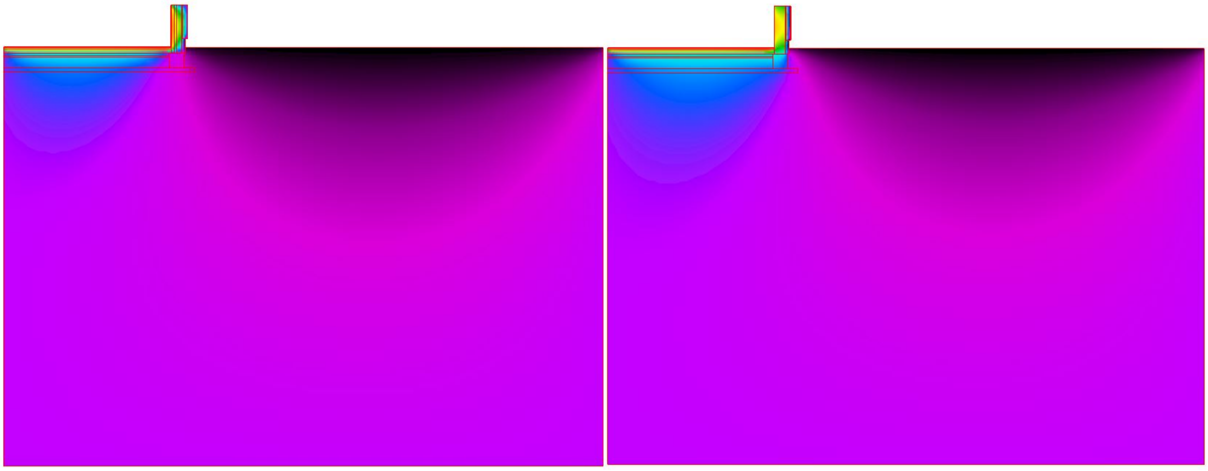


Figure 4.97_ Basement|Building|H (left), Basement|Staircase|H (right).

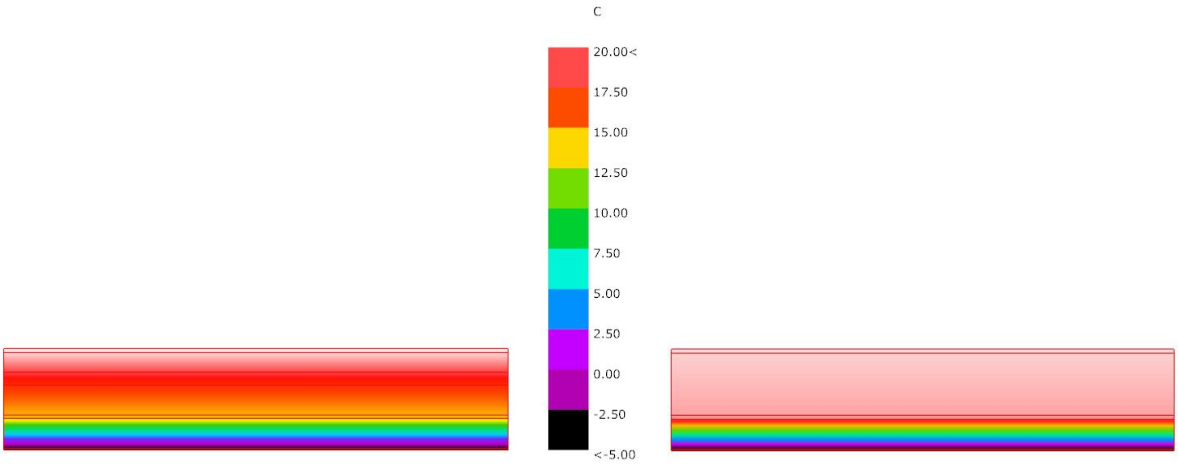


Figure 4.96_ Middle L.T.B.|Building|V (left), Middle L.T.B.|Staircase|V (right).

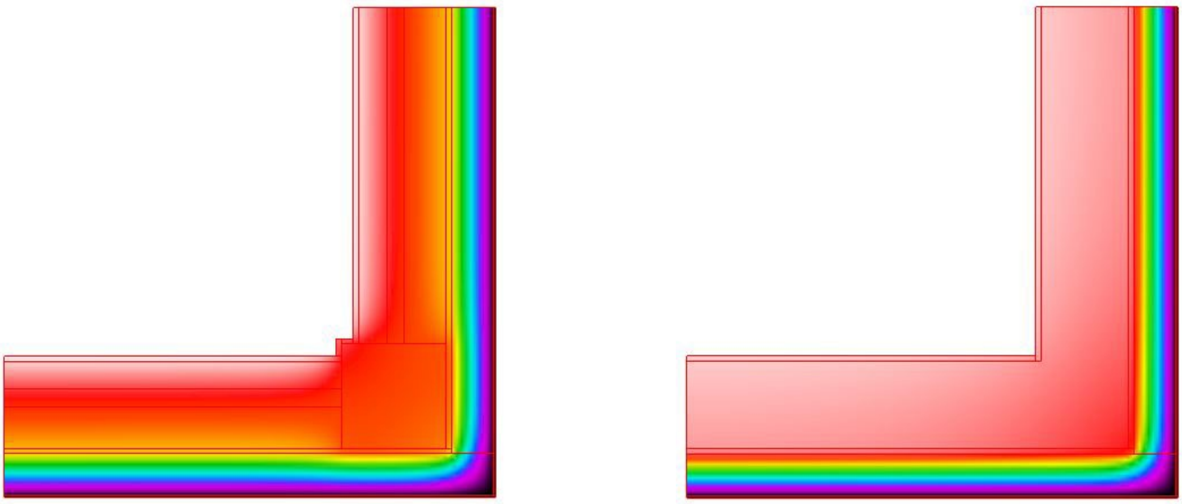


Figure 4.98_ Corner Panel/Panel|V (left), Corner Staircase|V (right).

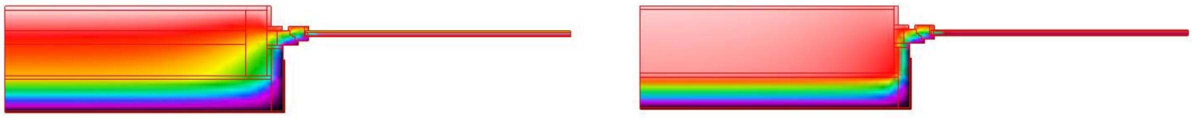


Figure 4.99_ Windows|Building|V (left), Windows|Staircase|V (right).

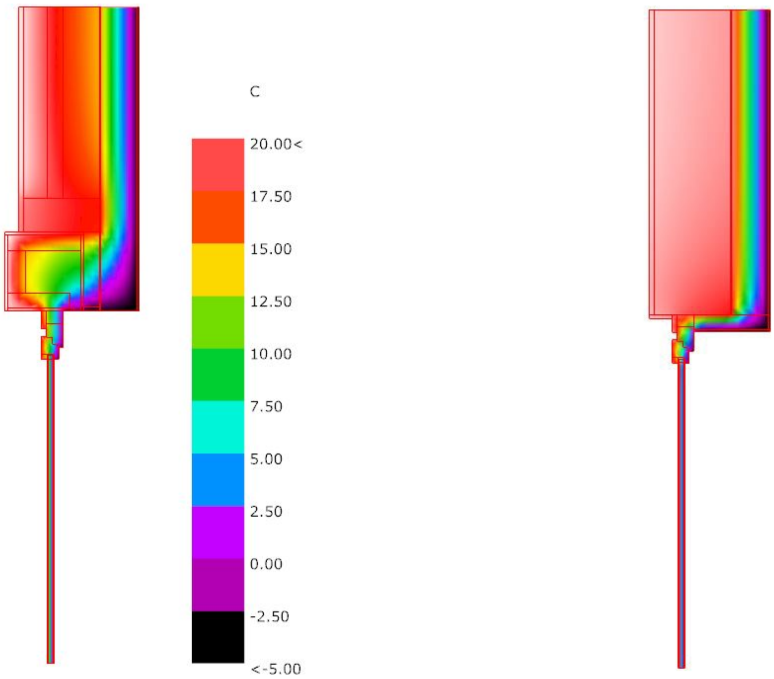


Figure 4.100_ Windows|Building UP|H (left), Windows|Staircase UP|H (right).

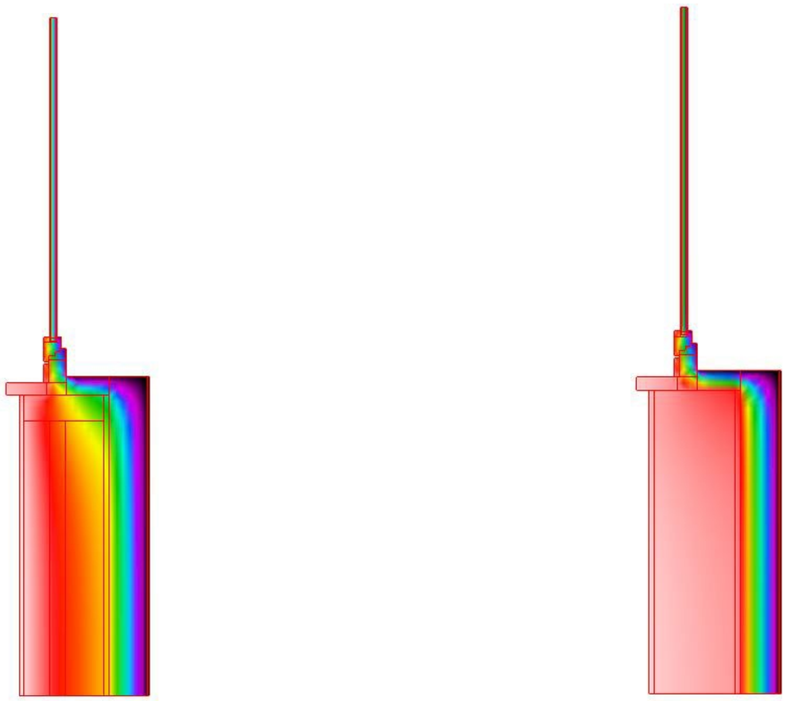


Figure 4.101_ Windows|Building DOWN|H (left), Windows|Staircase DOWN|H (right)

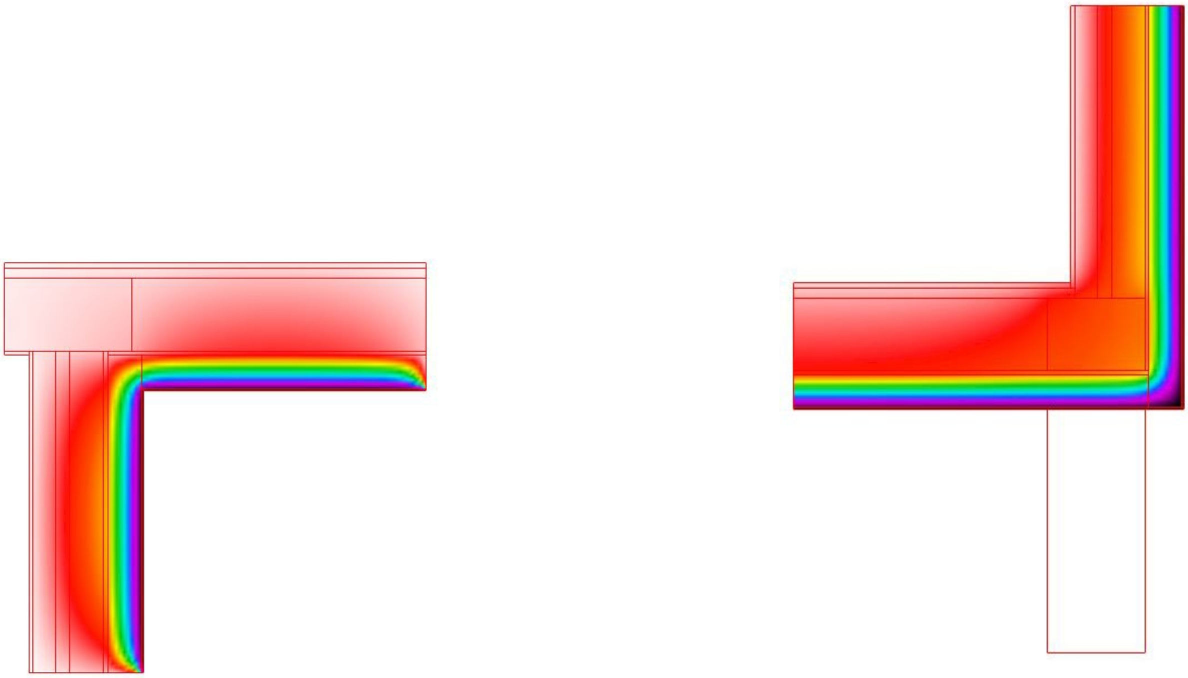


Figure 4.102_ Middle L.T.B.|Int. Overhang|H (left), Middle L.T.B.|Ext. Overhang|H (right).

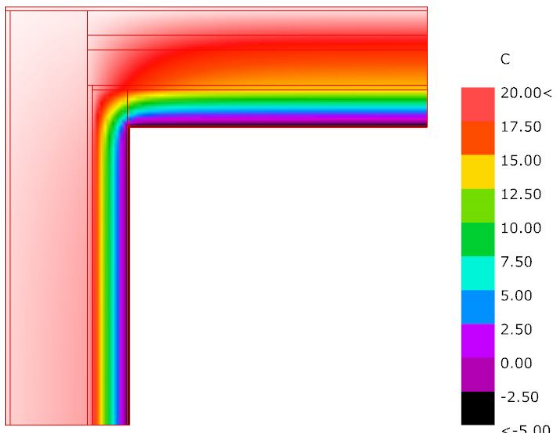


Figure 4.104_ Corner Staircase/Building|V.

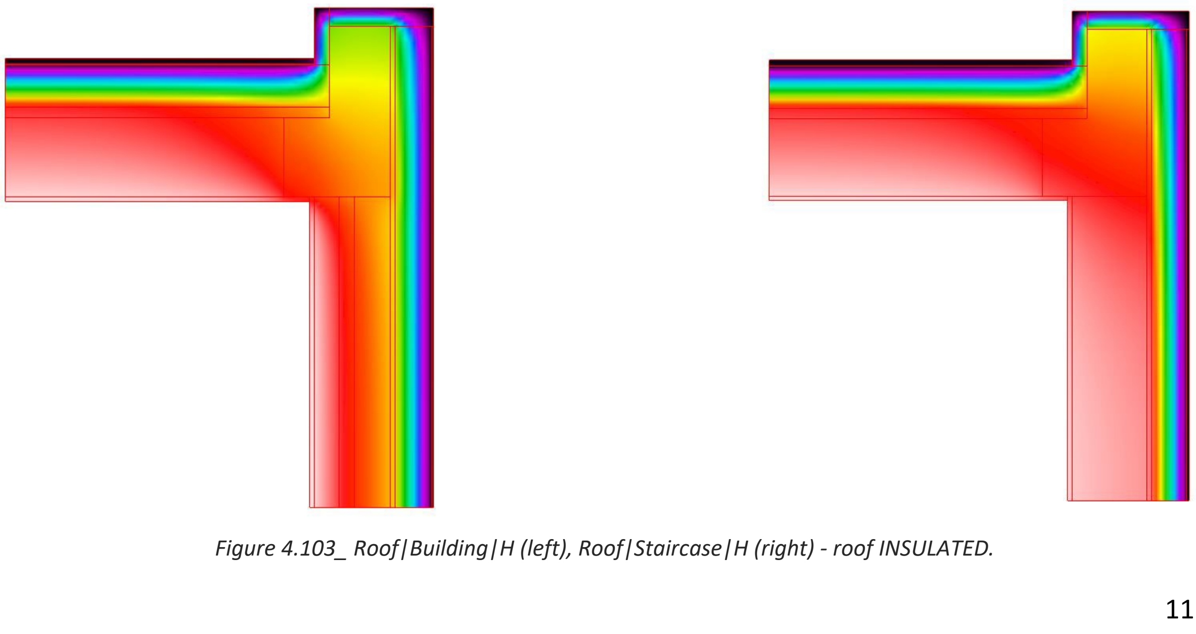


Figure 4.103_ Roof|Building|H (left), Roof|Staircase|H (right) - roof INSULATED.

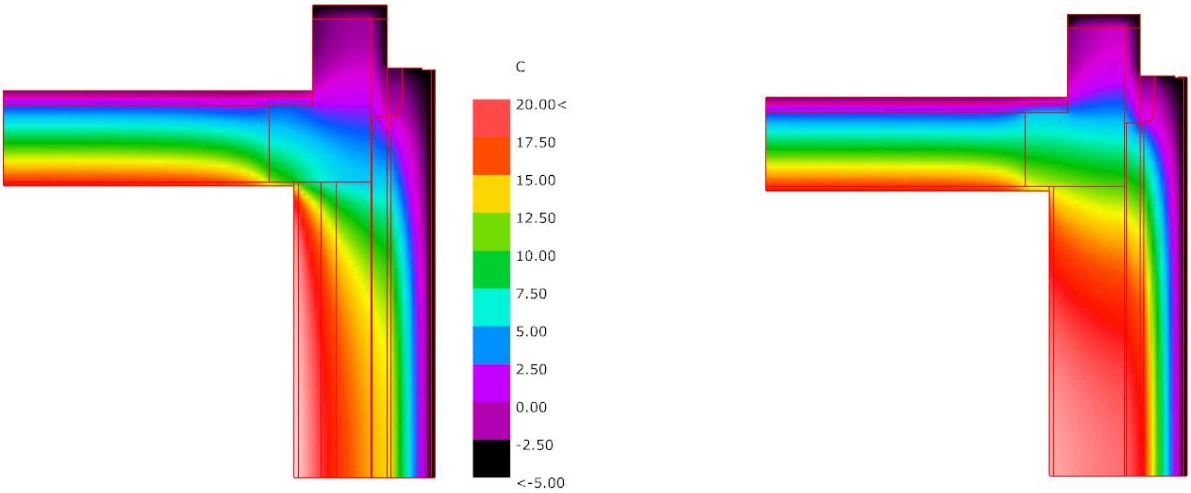


Figure 4.106_ Roof|Building|H (left), Roof|Staircase|H (right) – with NO insulated roof.

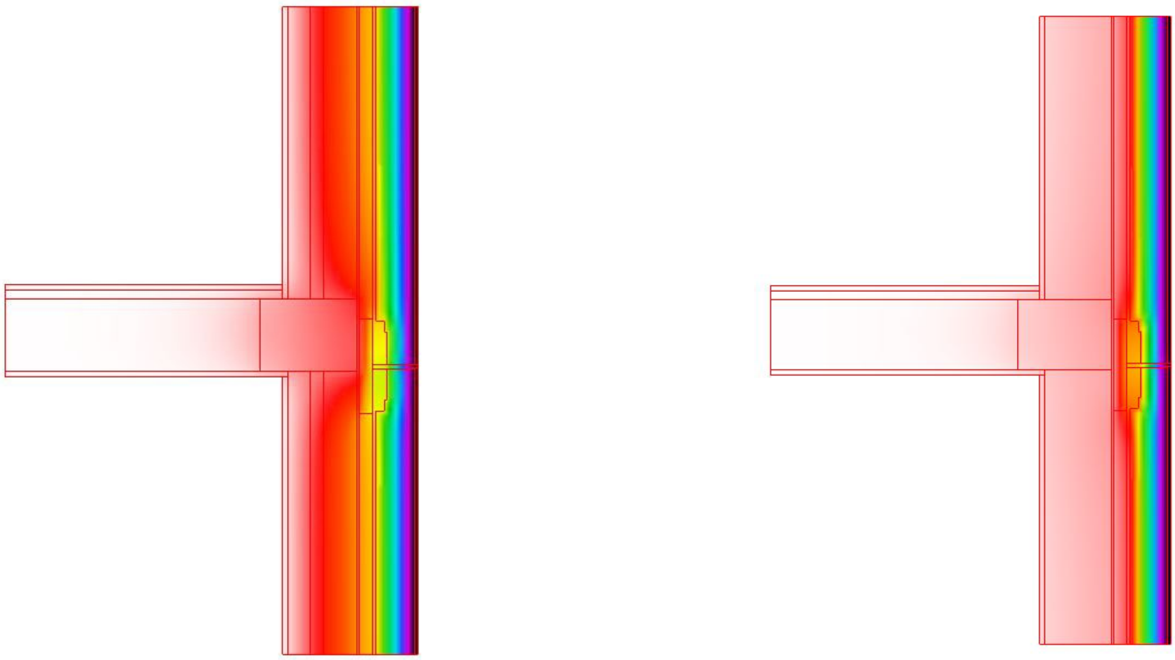


Figure 4.105_ Middle L.T.B.|Building|H (left), Middle L.T.B.|Staircase|H (right).

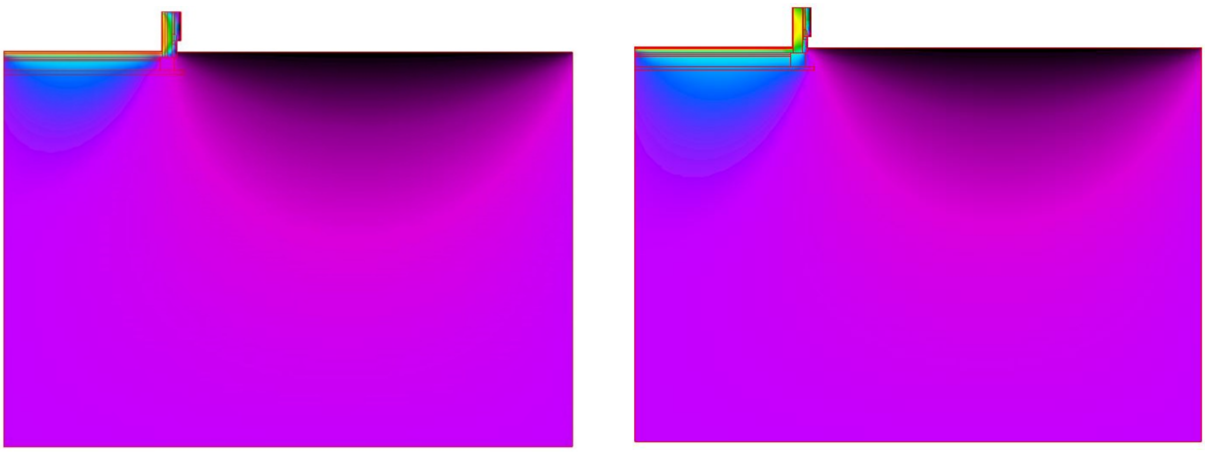


Figure 4.107_ Basement|Building|H (left), Basement|Staircase|H (right).

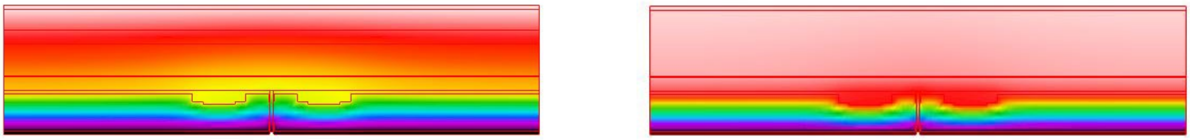


Figure 4.108_ Middle L.T.B.|Building|V (left), Middle L.T.B.|Staircase|V (right).

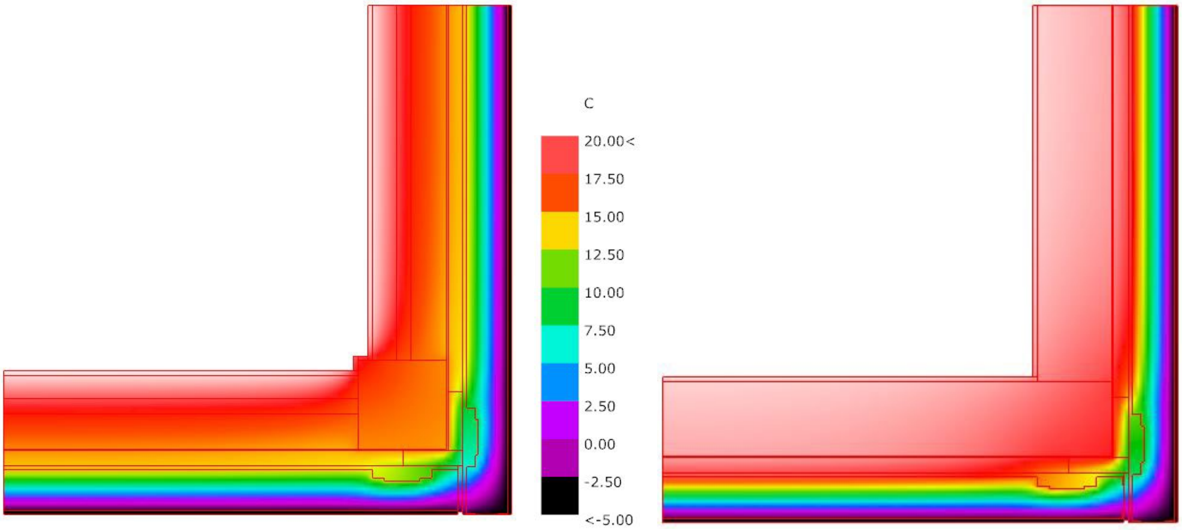


Figure 4.109_ Corner Panel/Panel|V (left), Corner Staircase|V (right).

Figure 4.110_ Windows|Building|V (left), Windows|Staircase|V (right).

Figure 4.112_ Windows|Building UP|H (left), Windows|Staircase UP|H (right).

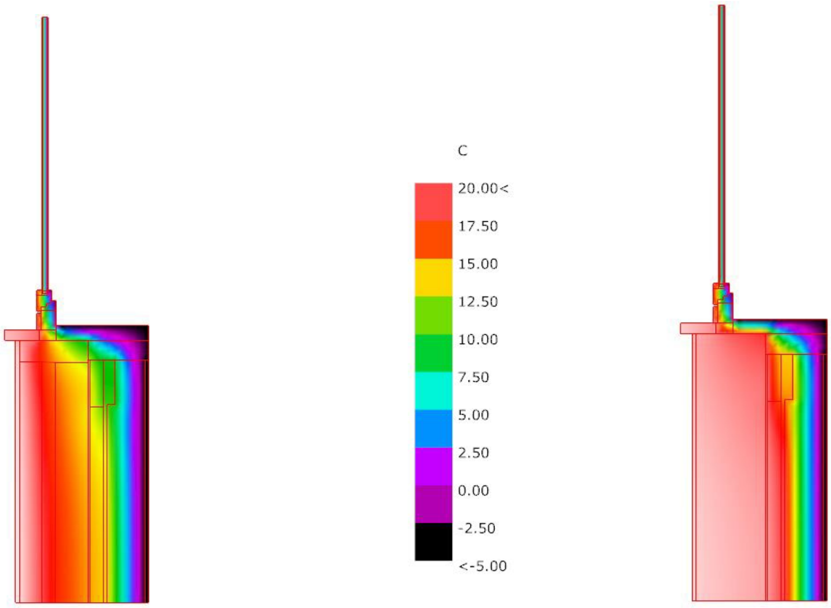


Figure 4.111_ Windows|Building DOWN|H (left), Windows|Staircase DOWN|H (right).

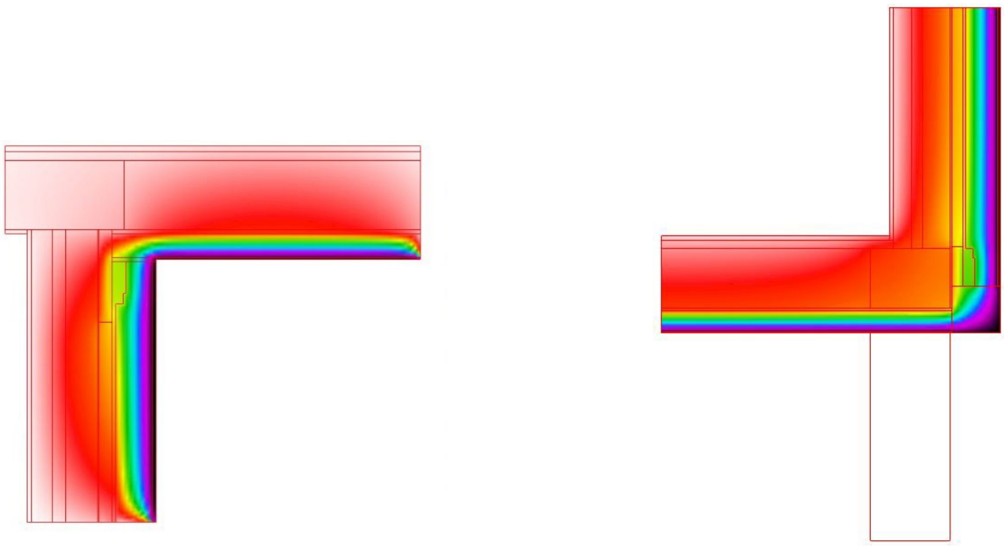


Figure 4.113_ Middle L.T.B.|Int. Overhang|H (left), Middle L.T.B.|Ext. Overhang|H (right).

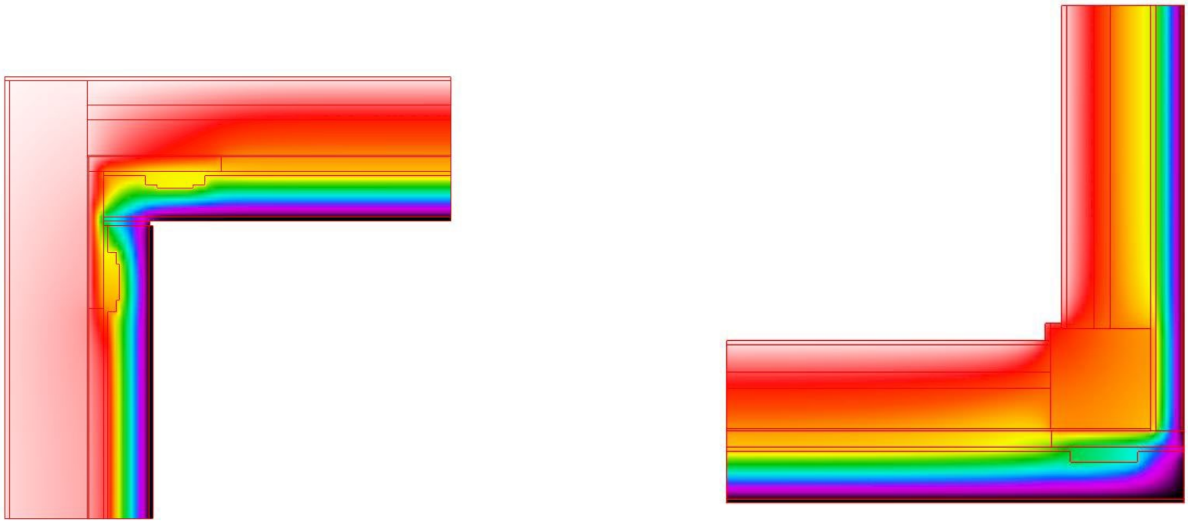


Figure 4.114_ Corner Staircase/Building|V (left), Corner ETICS/Panel|V (right).

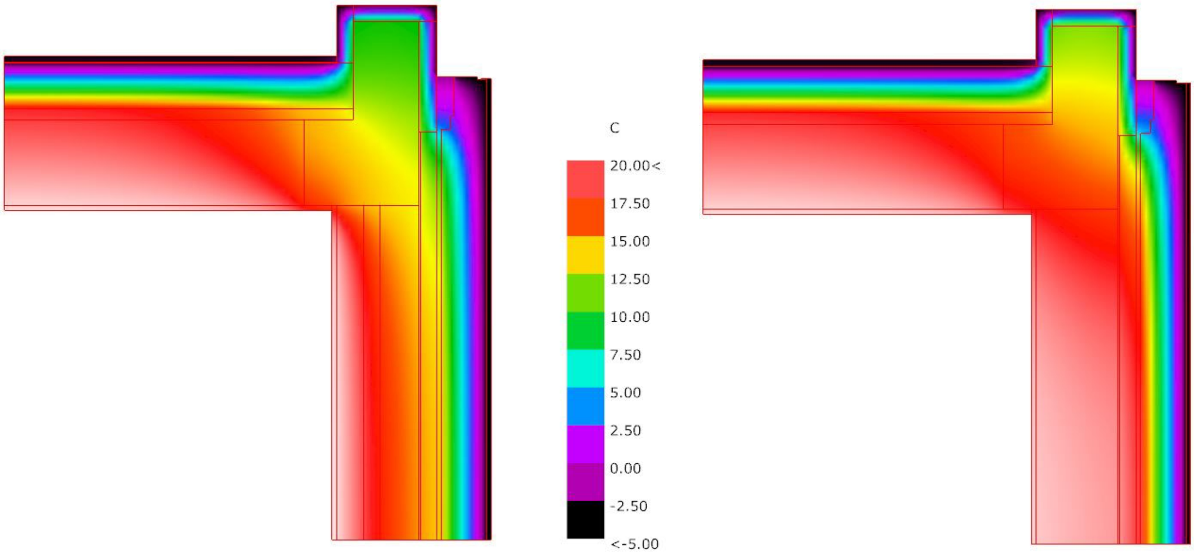


Figure 4.115_ Roof|Building|H (left), Roof|Staircase|H (right) - roof INSULATED.

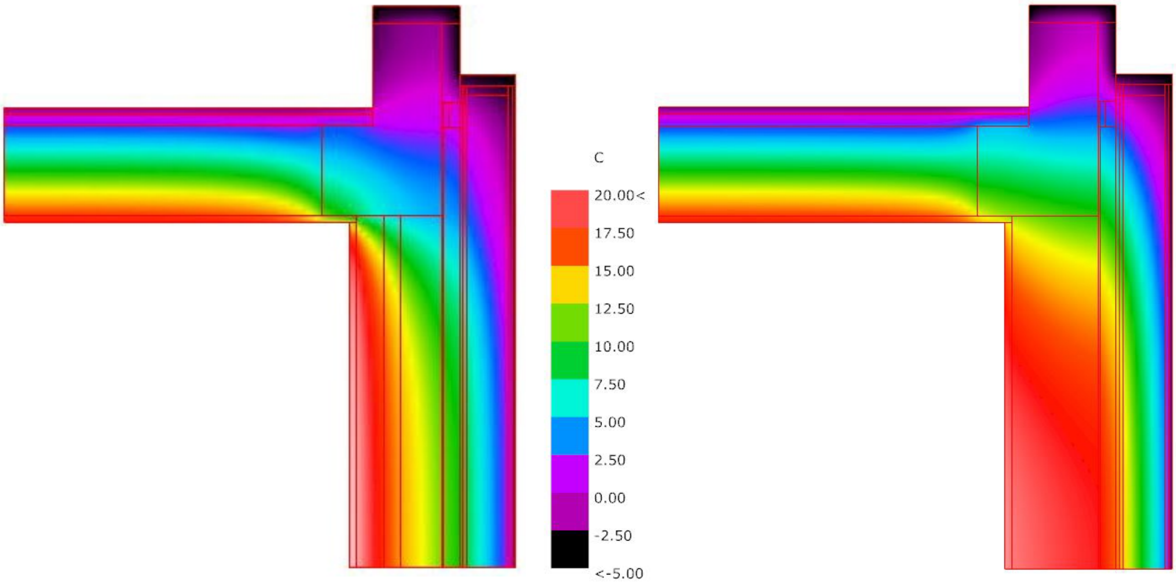


Figure 4.116_ Roof|Building|H (left), Roof|Staircase|H (right) – with NO insulated roof.

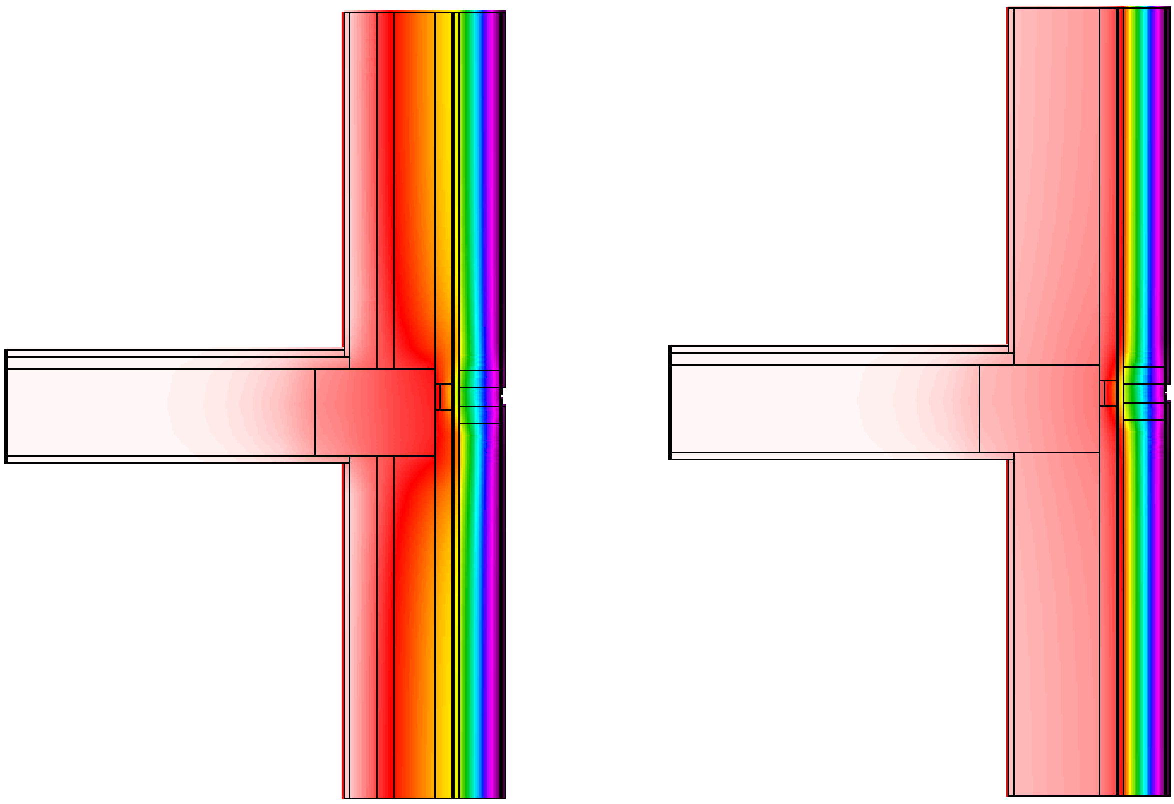


Figure 4.117_ Middle L.T.B.|Building|H (left), Middle L.T.B.|Staircase|H (right).

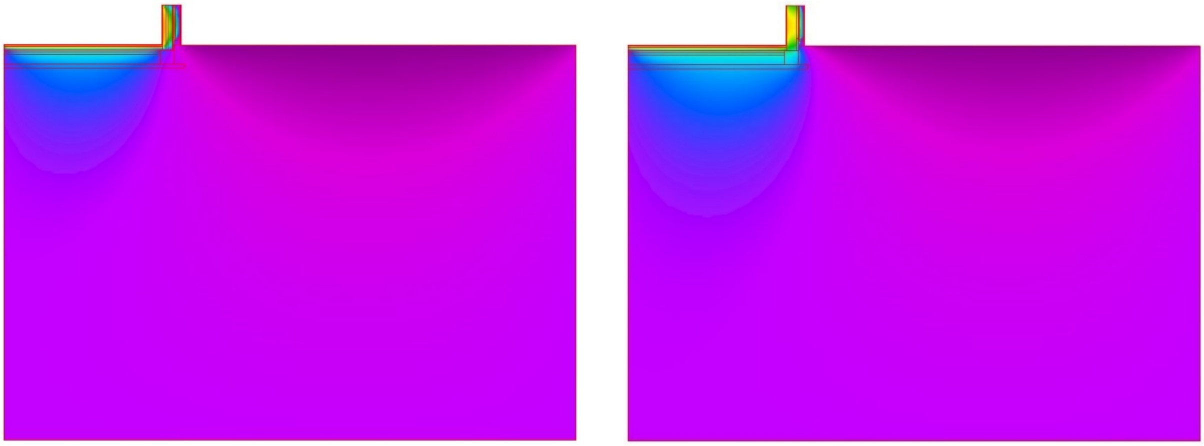


Figure 4.118_ Basement|Building|H (left), Basement|Staircase|H (right).

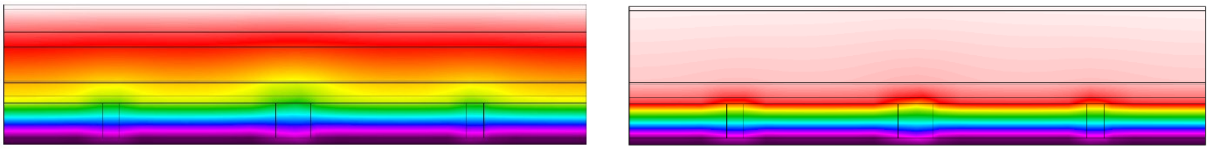


Figure 4.119_ Middle L.T.B.|Building|V (left), Middle L.T.B.|Staircase|V (right).

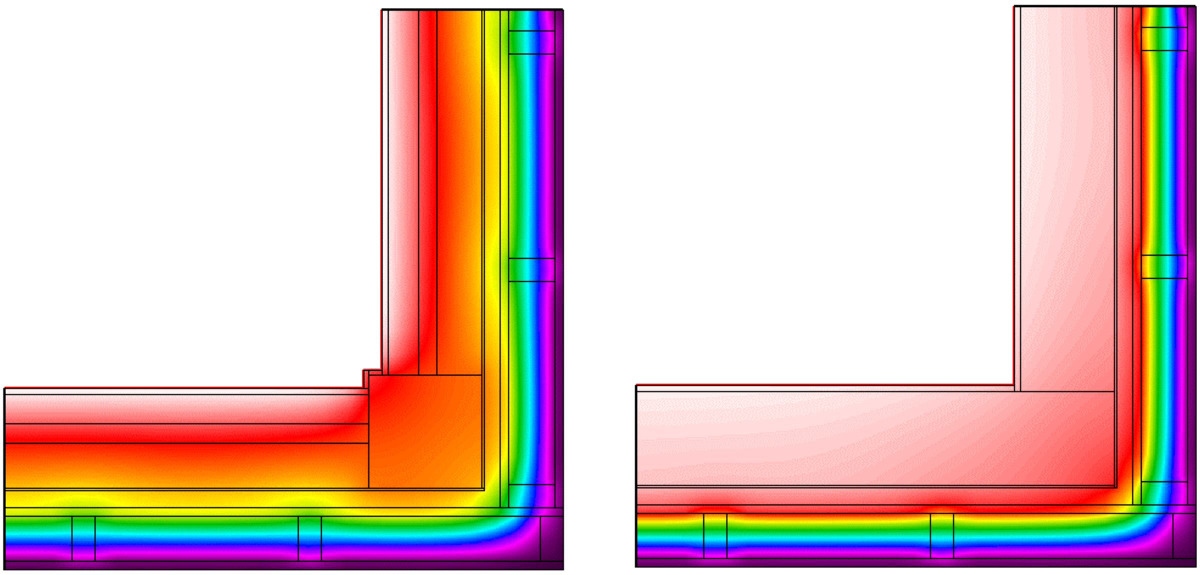


Figure 4.120_ Corner Panel/Panel|V (left), Corner Staircase|V (right).

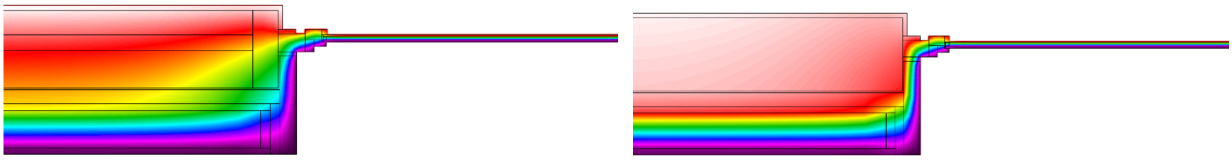


Figure 4.121_ Windows|Building|V (left), Windows|Staircase|V (right).

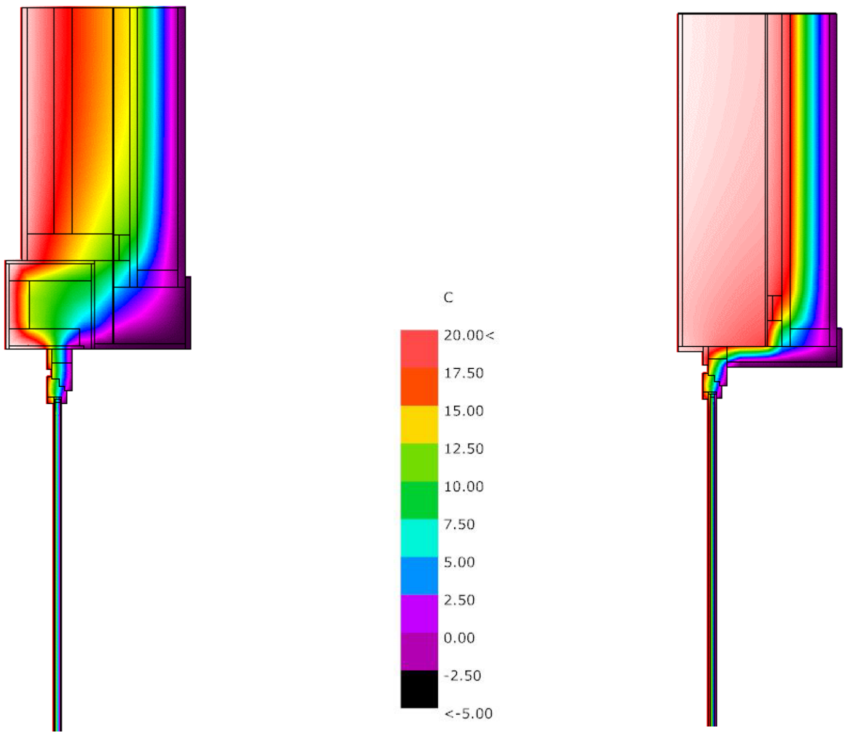


Figure 4.122_ Windows|Building UP|H (left), Windows|Staircase UP|H (right).

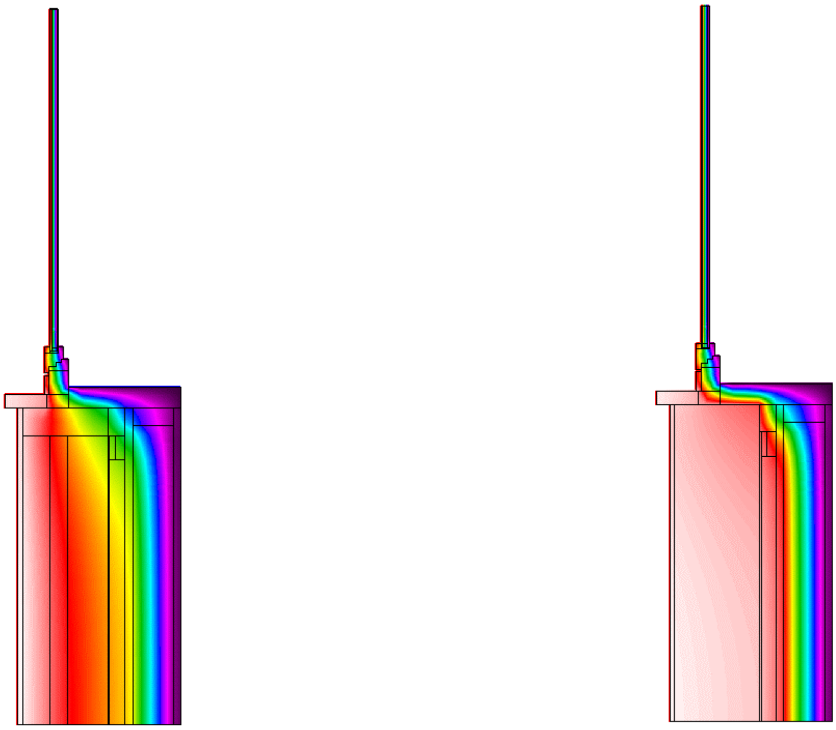


Figure 4.123_ Windows|Building DOWN|H (left), Windows|Staircase DOWN|H (right).

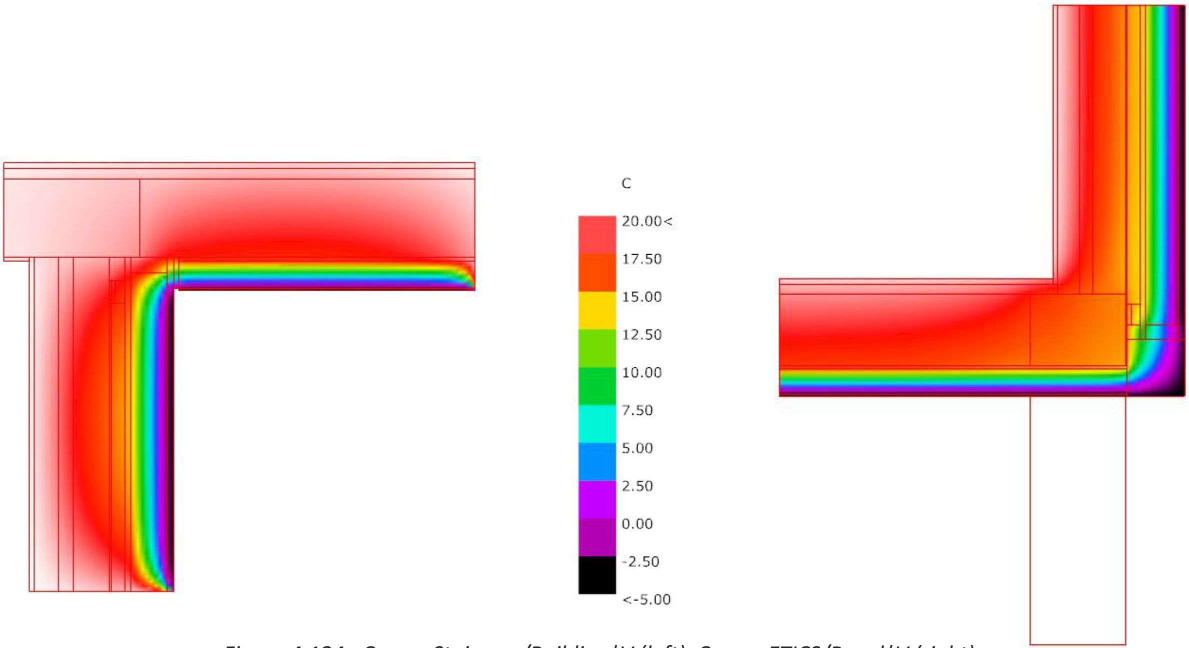


Figure 4.124_ Corner Staircase/Building|V (left), Corner ETICS/Panel|V (right).

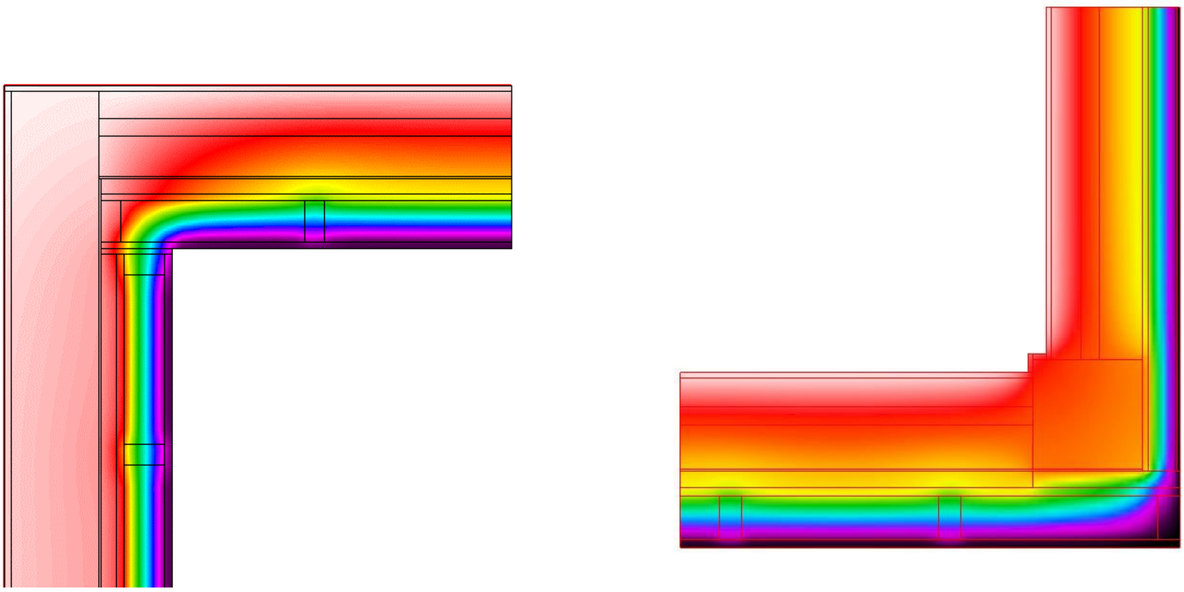


Figure 4.125_ Corner Staircase/Building|V (left), Corner ETICS/Panel|V (right).

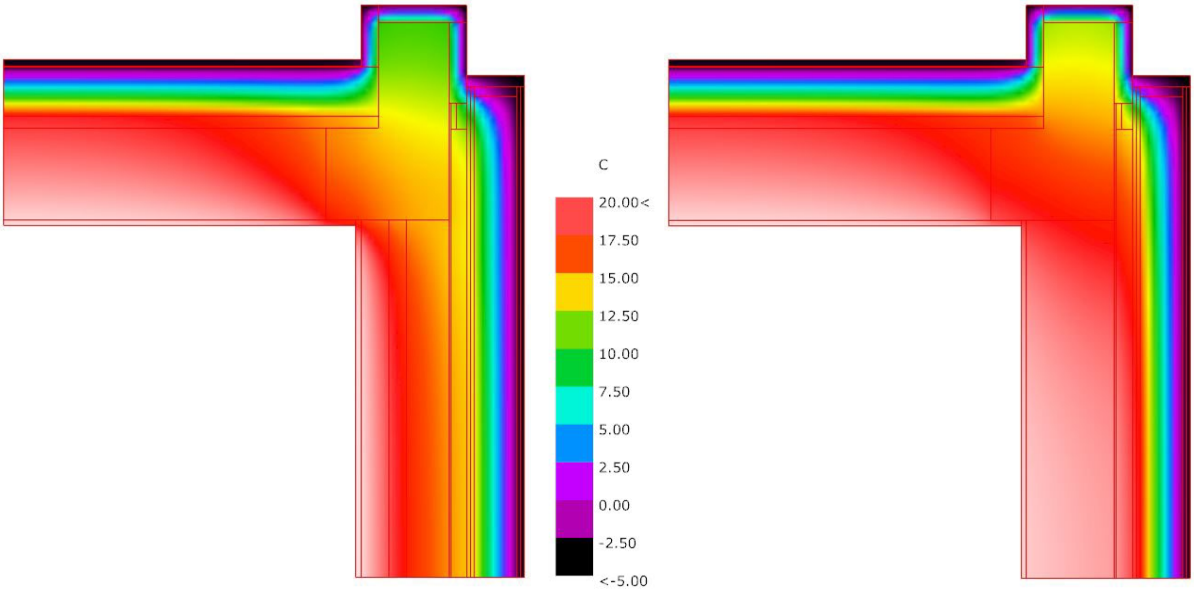


Figure 4.126_ Roof|Building|H (left), Roof|Staircase|H (right) - roof INSULATED.

The data necessary to calculate the linear thermal transmittance ψ_e were then exported to the reference Excel file (sheet "9_ ψ") in which the formulas previously described were applied.

In the table below a focus has been made on the calculation of ψ_e for wall/floor junctions.

LINEAR THERMAL TRANSMITTANCE FOR WALL/FLOOR JUNCTIONS									
INSIDE FLOOR LEVEL EQUAL TO OR HIGHER THAN OUTSIDE GROUND LEVEL									
TES WOOD PANEL		L_{2D} [W/mK]	h_W [m]	h_f [m]	U_W [W/m^{2}K]	Width [m]	B [m]	U_g [W/m^{2}K]	Ψ_e [W/mK]
CV04 - TES WOOD PANEL	Basement|Building|H	1.10	1.00	0.02	0.19	0.56	8.00	0.22	-0.07
CV08 - TES WOOD Panel STAIRCASE	Basement|Staircase|H	1.65	1.00	0.02	0.23	0.49	8.00	0.22	0.45
EASEE PANEL		L_{2D} [W/mK]	h_W [m]	h_f [m]	U_W [W/m^{2}K]	Width [m]	B [m]	U_g [W/m^{2}K]	Ψ_e [W/mK]
CV06 - EASEE Panel	Basement|Building|H	1.12	1.00	0.02	0.19	0.49	8.00	0.22	-0.04
CV07 - EASEE Panel STAIRCASE	Basement|Staircase|H	1.67	1.00	0.02	0.23	0.50	8.00	0.22	0.46
ETICS SYSTEM		L_{2D} [W/mK]	h_W [m]	h_f [m]	U_W [W/m^{2}K]	Width [m]	B [m]	U_g [W/m^{2}K]	Ψ_e [W/mK]
CV02 - BASE CASE + INSULATION	Basement|Building|H	1.13	1.00	0.02	0.21	0.41	8.00	0.22	-0.05
CV09 - ETICS STAIRCASE	Basement|Staircase|H	1.71	1.00	0.02	0.27	0.42	8.00	0.22	0.46
								EN ISO 10211:2017 (E) 12.4	

The data for the calculation of L_{2D} are reported in the following tables which show the values for all the analyzed nodes. **The cells highlighted in green are the data exported by Grasshopper**.

TES WOOD PANEL | **CUSTOM LENGTHS [m]**

N°	Node	L_{1e} - X axis [m]	L_{2e} - Y axis [m]	ΔT [°C]	Φ_{2D} [W]	Code L_1 (above/left)	Code L_2 (bottom/right)	U-value$_1$ [W/m²K]	L_{1e} (height) [m]	U-value$_2$ [W/m²K]	L_{2e} (height) [m]	$\Phi_{L.T.B.}$ [W]	Ψ_e [W/mK]
1	Roof|Building|H	1.48	1.34	25.00	63.83	CO01 - ROOF BASE CASE	CV04 - TES WOOD PANEL	1.54	1.48	0.19	1.34	0.32	0.01
2	Middle L.T.B.|Building|H	0.00	2.34	25.00	12.57	CV04 - TES WOOD PANEL	CV04 - TES WOOD PANEL	0.00	0.00	0.19	2.34	1.75	0.07
3	Basement|Building|H	4.48	1.60	25.00	27.57	-	-	-	-	-	-	-	-0.07
4	Middle L.T.B.|Building|V	2.02	0.00	25.00	10.65	CV04 - TES WOOD PANEL	CV04 - TES WOOD PANEL	0.19	2.02	0.00	0.00	1.31	0.05
5	Corner Panel/Panel |V	1.48	1.48	25.00	14.45	CV04 - TES WOOD PANEL	CV04 - TES WOOD PANEL	0.19	1.48	0.19	1.48	0.74	0.03
6	Windows|Building|V	0.95	1.15	25.00	46.61	CV04 - TES WOOD PANEL	WINDOW/LATERAL	0.19	0.95	1.41	1.15	1.52	0.06
7	Windows|Building UP|H	1.00	1.16	25.00	48.02	CV04 - TES WOOD PANEL	WINDOW/BOTTOM	0.19	1.00	1.43	1.16	2.04	0.08
8	Windows|Building DOWN|H	0.94	1.18	25.00	45.68	CV04 - TES WOOD PANEL	WINDOW/BOTTOM	0.19	0.94	1.43	1.18	-0.87	-0.03
9	Roof|Building|H	1.48	1.47	25.00	18.52	CO03 - ROOF BASE CASE + INSULATION	CV04 - TES WOOD PANEL	0.22	1.48	0.19	1.47	3.56	0.14
10	Middle L.T.B.|Int. Overhang|H	1.00	1.00	25.00	19.13	CV10 - ETICS OVERHANG	CV04 - TES WOOD PANEL	0.25	1.00	0.19	1.00	8.32	0.33
11	Middle L.T.B.|Ext. Overhang|H	1.48	1.43	25.00	16.41	CV10 - ETICS OVERHANG	CV04 - TES WOOD PANEL	0.25	1.48	0.19	1.43	0.67	0.03
12	Corner ETICS/Panel |V	1.37	1.48	25.00	16.34	CV04 - TES WOOD PANEL	CV02 - BASE CASE + INSULATION	0.19	1.37	0.21	1.48	2.30	0.09
13	Corner Staircase/Building |V	1.00	1.00	25.00	13.05	CV04 - TES WOOD PANEL	CV08 - TES WOOD Panel STAIRCASE	0.19	1.00	0.23	1.00	2.63	0.11
14	Roof|Staircase|H	1.48	1.34	25.00	76.30	CO01 - ROOF BASE CASE	CV08 - TES WOOD Panel STAIRCASE	1.54	1.48	0.23	1.34	11.25	0.45
15	Middle L.T.B.|Staircase|H	0.00	2.34	25.00	14.86	CV08 - TES WOOD Panel STAIRCASE	CV08 - TES WOOD Panel STAIRCASE	0.00	0.00	0.23	2.34	1.35	0.05
16	Basement|Staircase|H	4.48	1.60	25.00	41.30	-	-	-	-	-	-	-	0.45
17	Middle L.T.B.|Staircase|V	2.02	0.00	25.00	13.84	CV08 - TES WOOD Panel STAIRCASE	CV08 - TES WOOD Panel STAIRCASE	0.23	2.02	0.00	0.00	2.18	0.09
18	Corner Staircase |V	1.48	1.48	25.00	17.98	CV08 - TES WOOD Panel STAIRCASE	CV08 - TES WOOD Panel STAIRCASE	0.23	1.48	0.23	1.48	0.85	0.03
19	Windows|Staircase|V	0.95	1.15	25.00	49.81	CV08 - TES WOOD Panel STAIRCASE	WINDOW/LATERAL	0.23	0.95	1.41	1.15	3.63	0.15
20	Windows|Staircase UP|H	1.00	1.16	25.00	49.18	CV08 - TES WOOD Panel STAIRCASE	WINDOW/BOTTOM	0.23	1.00	1.43	1.16	2.05	0.08
21	Windows|Staircase DOWN|H	0.94	1.18	25.00	49.60	CV08 - TES WOOD Panel STAIRCASE	WINDOW/BOTTOM	0.23	0.94	1.43	1.18	1.97	0.08
22	Roof|Staircase|H	1.48	1.47	25.00	20.81	CO03 - ROOF BASE CASE + INSULATION	CV08 - TES WOOD Panel STAIRCASE	0.22	1.48	0.23	1.47	4.15	0.17

EASEE PANEL | **CUSTOM LENGTHS [m]**

N°	Node	L_{1e} - X axis [m]	L_{2e} - Y axis [m]	ΔT [°C]	Φ_{2D} [W]	Code L_1 (above/left)	Code L_2 (bottom/right)	U-value$_1$ [W/m²K]	L_{1e} (height) [m]	U-value$_2$ [W/m²K]	L_{2e} (height) [m]	$\Phi_{L.T.B.}$ [W]	Ψ_e [W/mK]
1	Roof|Building|H	1.49	1.34	25.00	62.41	CO01 - ROOF BASE CASE	CV06 - EASEE Panel	1.54	1.49	0.19	1.34	-1.18	-0.05
2	Middle L.T.B.|Building|H	0.00	2.34	25.00	12.14	CV06 - EASEE Panel	CV06 - EASEE Panel	0.00	0.00	0.19	2.34	1.21	0.05
3	Basement|Building|H	4.49	1.60	25.00	28.06	-	-	-	-	-	-	-	-0.04
4	Middle L.T.B.|Building|V	2.02	0.00	25.00	10.48	CV06 - EASEE Panel	CV06 - EASEE Panel	0.19	2.02	0.00	0.00	1.05	0.04
5	Corner Panel/Panel |V	1.72	1.72	25.00	16.53	CV06 - EASEE Panel	CV06 - EASEE Panel	0.19	1.72	0.19	1.72	0.42	0.02
6	Windows|Building|V	1.00	1.16	25.00	47.83	CV06 - EASEE Panel	WINDOW/LATERAL	0.19	1.00	1.41	1.16	2.17	0.09
7	Windows|Building UP|H	1.00	1.16	25.00	48.64	CV06 - EASEE Panel	WINDOW/BOTTOM	0.19	1.00	1.43	1.16	2.62	0.10
8	Windows|Building DOWN|H	1.18	0.96	25.00	47.80	WINDOW/BOTTOM	CV06 - EASEE Panel	1.43	1.18	0.19	0.96	1.10	0.04
9	Roof|Building|H	1.49	1.48	25.00	20.14	CO03 - ROOF BASE CASE + INSULATION	CV06 - EASEE Panel	0.22	1.49	0.19	1.48	5.05	0.20
10	Middle L.T.B.|Int. Overhang|H	1.00	0.99	25.00	18.74	CV10 - ETICS OVERHANG	CV06 - EASEE Panel	0.25	1.00	0.19	0.99	7.92	0.32
11	Middle L.T.B.|Ext. Overhang|H	1.49	1.43	25.00	16.30	CV10 - ETICS OVERHANG	CV06 - EASEE Panel	0.25	1.49	0.19	1.43	0.46	0.02
12	Corner ETICS/Panel |V	1.37	1.49	25.00	16.47	CV06 - EASEE Panel	CV02 - BASE CASE + INSULATION	0.19	1.37	0.21	1.49	2.32	0.09
13	Corner Staircase/Building |V	1.00	1.00	25.00	12.98	CV06 - EASEE Panel	CV07 - EASEE Panel STAIRCASE	0.19	1.00	0.23	1.00	2.43	0.10
14	Roof|Staircase|H	1.49	1.34	25.00	73.00	CO01 - ROOF BASE CASE	CV07 - EASEE Panel STAIRCASE	1.54	1.49	0.23	1.34	7.83	0.31
15	Middle L.T.B.|Staircase|H	0.00	2.34	25.00	14.65	CV07 - EASEE Panel STAIRCASE	CV07 - EASEE Panel STAIRCASE	0.00	0.00	0.23	2.34	0.96	0.04
16	Basement|Staircase|H	4.49	1.60	25.00	41.83	-	-	-	-	-	-	-	0.46
17	Middle L.T.B.|Staircase|V	2.02	0.00	25.00	13.53	CV07 - EASEE Panel STAIRCASE	CV07 - EASEE Panel STAIRCASE	0.23	2.02	0.00	0.00	1.72	0.07
18	Corner Staircase |V	1.72	1.72	25.00	20.26	CV07 - EASEE Panel STAIRCASE	CV07 - EASEE Panel STAIRCASE	0.23	1.72	0.23	1.72	0.07	0.00
19	Windows|Staircase|V	1.00	1.16	25.00	51.99	CV07 - EASEE Panel STAIRCASE	WINDOW/LATERAL	0.23	1.00	1.41	1.16	5.14	0.21
20	Windows|Staircase UP|H	1.00	1.16	25.00	49.90	CV07 - EASEE Panel STAIRCASE	WINDOW/BOTTOM	0.23	1.00	1.43	1.16	2.69	0.11
21	Windows|Staircase DOWN|H	1.18	0.96	25.00	50.60	WINDOW/BOTTOM	CV07 - EASEE Panel STAIRCASE	1.43	1.18	0.23	0.96	2.77	0.11
22	Roof|Staircase|H	1.49	1.48	25.00	22.92	CO03 - ROOF BASE CASE + INSULATION	CV07 - EASEE Panel STAIRCASE	0.22	1.49	0.23	1.48	6.09	0.24

ETICS SYSTEM		CUSTOM LENGTHS [m]											
N°	Node	L_{1e} - X axis [m]	L_{2e} - Y axis [m]	ΔT [°C]	Φ_{2D} [W]	Code L_1 (above/left)	Code L_2 (bottom/right)	U-value$_1$ [W/m²K]	L_{1e} (height) [m]	U-value$_2$ [W/m²K]	L_{2e} (height) [m]	$\Phi_{L.T.B.}$ [W]	Ψ_e [W/mK]
1	Roof|Building|H	1.41	1.34	25.00	62.25	CO01 - ROOF BASE CASE	CV02 - BASE CASE + INSULATION	1.54	1.41	0.21	1.34	0.98	0.04
2	Middle L.T.B.|Building|H	0.00	2.33	25.00	12.96	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.00	0.00	0.21	2.33	0.77	0.03
3	Basement|Building|H	4.41	1.60	25.00	28.30	-	-	-	-	-	-	-	-0.05
4	Middle L.T.B.|Building|V	2.02	0.00	25.00	10.63	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.21	2.02	0.00	0.00	0.11	0.00
5	Corner Panel/Panel |V	1.41	1.41	25.00	14.14	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.21	1.41	0.21	1.41	-0.55	-0.02
6	Windows|Building|V	1.02	1.14	25.00	47.03	CV02 - BASE CASE + INSULATION	WINDOW/LATERAL	0.21	1.02	1.41	1.14	1.29	0.05
7	Windows|Building UP|H	1.00	1.16	25.00	49.09	CV02 - BASE CASE + INSULATION	WINDOW/BOTTOM	0.21	1.00	1.43	1.16	2.52	0.10
8	Windows|Building DOWN|H	1.18	0.94	25.00	47.75	WINDOW/BOTTOM	CV02 - BASE CASE + INSULATION	1.43	1.18	0.21	0.94	0.65	0.03
9	Roof|Building|H	1.41	1.48	25.00	17.98	CO03 - ROOF BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.22	1.41	0.21	1.48	2.53	0.10
10	Middle L.T.B.|Int. Overhang|H	1.00	0.99	25.00	16.45	CV10 - ETICS OVERHANG	CV02 - BASE CASE + INSULATION	0.25	1.00	0.21	0.99	5.09	0.20
11	Middle L.T.B.|Ext. Overhang|H	1.41	1.46	25.00	15.10	CV10 - ETICS OVERHANG	CV02 - BASE CASE + INSULATION	0.25	1.41	0.21	1.46	-1.18	-0.05
12	Corner ETICS/Panel |V	1.41	1.41	25.00	14.14	CV02 - BASE CASE + INSULATION	CV02 - BASE CASE + INSULATION	0.21	1.41	0.21	1.41	-0.55	-0.02
13	Corner Staircase/Building |V	1.00	1.00	25.00	12.85	CV02 - BASE CASE + INSULATION	CV09 - ETICS STAIRCASE	0.21	1.00	0.27	1.00	0.90	0.04
14	Roof|Staircase|H	1.41	1.34	25.00	72.64	CO01 - ROOF BASE CASE	CV09 - ETICS STAIRCASE	1.54	1.41	0.27	1.34	9.35	0.37
15	Middle L.T.B.|Staircase|H	0.00	2.33	25.00	15.94	CV09 - ETICS STAIRCASE	CV09 - ETICS STAIRCASE	0.00	0.00	0.27	2.33	0.21	0.01
16	Basement|Staircase|H	4.41	1.60	25.00	42.64	-	-	-	-	-	-	-	0.46
17	Middle L.T.B.|Staircase|V	2.02	0.00	25.00	13.80	CV09 - ETICS STAIRCASE	CV09 - ETICS STAIRCASE	0.27	2.02	0.00	0.00	0.24	0.01
18	Corner Staircase |V	1.41	1.41	25.00	17.51	CV09 - ETICS STAIRCASE	CV09 - ETICS STAIRCASE	0.27	1.41	0.27	1.41	-1.43	-0.06
19	Windows|Staircase|V	1.02	1.14	25.00	50.29	CV09 - ETICS STAIRCASE	WINDOW/LATERAL	0.27	1.02	1.41	1.14	3.01	0.12
20	Windows|Staircase UP|H	1.00	1.16	25.00	50.37	CV09 - ETICS STAIRCASE	WINDOW/BOTTOM	0.27	1.00	1.43	1.16	2.29	0.09
21	Windows|Staircase DOWN|H	1.18	0.94	25.00	50.66	WINDOW/BOTTOM	CV09 - ETICS STAIRCASE	1.43	1.18	0.27	0.94	2.13	0.09
22	Roof|Staircase|H	1.41	1.48	25.00	20.23	CO03 - ROOF BASE CASE + INSULATION	CV09 - ETICS STAIRCASE	0.22	1.41	0.27	1.48	2.55	0.10

In the Grasshopper file, the ψ_k values of the analyzed nodes are then added to the surfaces (A_i) dispersions, after having been multiplied by the respective lengths of the linear thermal bridges (l_k).

Figure 4.127_ Assignment of the linear thermal bridges to the respective elements.

At this point the average thermal transmittance was calculated for each of the 7 elements analysed, according to the formula:

$$U_{average_{TOT}} = \frac{A \times U + \sum_{k=1}^{N_j} \psi_k \times l_k}{A_{TOT}} \quad \left[\frac{W}{m^2 \times K}\right]$$

As the last step, H_D was then calculated as:

$$H_D = \Sigma_i A_i U_i + \Sigma_k l_k \psi_k$$

TES WOOD PANEL

Elements	Tot. Surface Area [m²]	A*U [W/K]	FINAL OUTPUT	$U_{average}$TOT [W/m²K]	H_D [W/K]
Roof	795.79	175.30		0.24	193.73
Perimetral Walls	2669.73	494.81		0.26	689.07
Windows	366.64	557.31		1.52	557.31
ETICS | Vertical	664.72	138.77		0.25	165.77
ETICS | Horizontal	280.68	58.60		0.32	90.64
French Doors	386.40	587.35		1.52	587.35
Balconies	460.18	710.70		1.54	710.70
Tot. Results	5624.14	2722.83			2994.57

EASEE PANEL

Elements	Tot. Surface Area [m²]	A*U [W/K]	FINAL OUTPUT	$U_{average}$TOT [W/m²K]	H_D [W/K]
Roof	795.79	175.30		0.25	201.64
Perimetral Walls	2669.73	499.91		0.30	800.44
Windows	366.64	557.31		1.52	557.31
ETICS | Vertical	664.72	138.77		0.25	166.06
ETICS | Horizontal	280.68	58.60		0.31	86.32
French Doors	386.40	587.35		1.52	587.35
Balconies	460.18	710.70		1.54	710.70
Tot. Results	5624.14	2727.94			3109.82

ETICS SYSTEM

Elements	Tot. Surface Area [m²]	A*U [W/K]	FINAL OUTPUT	$U_{average}$TOT [W/m²K]	H_D [W/K]
Roof	795.79	175.30		0.24	187.92
Perimetral Walls	2681.69	559.84		0.26	709.03
Windows	366.64	557.31		1.52	557.31
ETICS | Vertical	664.72	138.77		0.20	132.35
ETICS | Horizontal	280.68	58.60		0.26	72.46
French Doors	386.40	587.35		1.52	587.35
Balconies	460.18	710.70		1.54	710.70
Tot. Results	5636.10	2787.87			2957.13

Table 4.10_ Final calculation of H_D

Calculation of H_g

The heat transfer via the ground is characterized by:

- Heat flow related to the area of the ground, depending on the construction of the floor;
- Heat flow related to the perimeter of the floor, depending on the thermal bridging at the edge of the floor, and
- Annual periodic heat floor, also related to the perimeter of the floor, resulting from the thermal inertia of the ground.

The steady-state, or annual average, part of the heat transfer has been evaluated using the area-related heat transfer calculated by the formulae given in EN ISO 13370:2017 (E)[76] - *Chapter 7*, together with the edge-related heat transfer obtained from linear thermal transmittance that is in accordance with any methods in ISO 14683 (numerical methods, thermal bridge catalogues, manual calculation or default values).

We considered a floor with vertical edge insulation, that is why the formulae of the thermal transmittance in EN ISO 13370:2017 – *Annex E* has been corrected using the procedure in *Annex D*.

The steady-state part of the heat transfer is given by the formula:

$$H_g = A \times U + P \times (\psi_{wf} + \psi_{g;ed})$$

Where:

- H_g is the steady-state heat transfer coefficient via the ground (W/K);
- *A* is the area of the floor (m^2);
- *U* is the thermal transmittance between the internal and external environment ($U_{fg;sog}$; $U_{fg;sus}$; $U_{bg;eff}$ *or* U_{ub}, depending on floor type (W/m^{2}K);
- *P* is the exposed perimeter (m);
- ψ_{wf} is the linear thermal transmittance of the wall/floor junction (W/mK);
- $\psi_{g;ed}$ is the linear thermal transmittance of the edge insulation (W/mK).

In our case we calculated $U_{fg;sog}$ that is the thermal transmittance of slab on the ground floor, including the effect of the ground.

To allow for the three-dimensional nature of heat flow within the ground, the formulae are expressed in terms of the "characteristic dimension" of floor *B*, defined as:

$$B = \frac{A}{0.5 \times P} \quad [m]$$

Where:

- *B* is the characteristic dimension of the floor (m);
- *A* is the area of the floor (m^2);
- *P* is the exposed perimeter (m).

To simplify the expression of the thermal transmittance is introduced also the concept of "equivalent thickness". The thermal resistance of the ground is represented by its equivalent thickness. It is defined:

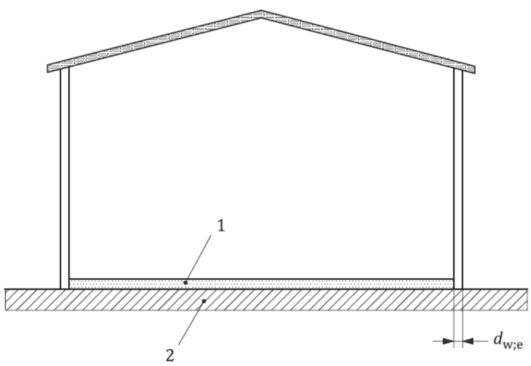
- d_f as the equivalent thickness for floors;
- $d_{w,b}$ as the equivalent thickness for walls of basements below ground level.

The total equivalent thickness d_f is defined by:

$$d_f = d_{w;e} + \lambda_g \times (R_{si} + R_{f;sog} + R_{se})$$

Where:

- $d_{w;e}$ is the full thickness of the walls, including all layers (m);
- λ_g is the thermal conductivity of the ground (W/mK);
- $R_{f;sog}$ is the thermal resistance of the floor slab (m^{2}K/W);
- R_{si} is the thermal resistance of internal surface (m^{2}K/W);
- R_{se} is the thermal resistance of the external surface (m^{2}K/W).



Key
1 floor slab
2 ground
$d_{w;e}$ thickness of external walls

Figure 4.128_ Schematic diagram of slab on ground floor. Credits: EN ISO 13370:2017 (E)

For the thermal properties of the ground, we referred to the following table:

Category	Description	Thermal conductivity λ_g W/(m·K)	Heat capacity per volume ρc J/(m³·K)
1	clay or silt	1,5	$3{,}0 \times 10^6$
2	sand or gravel	2,0	$2{,}0 \times 10^6$
3	homogeneous rock	3,5	$2{,}0 \times 10^6$

Table 4.11_ Thermal properties of the ground.
Credits: EN ISO 13370:2017 (E)

If the ground is unknown, category 2 should be used.

Depending on the thermal insulation of the floor we calculated $U_{fg;sog;0}$:

- If $d_f < B$ (uninsulated and moderately insulated floors),

$$U_{fg;sog;0} = \frac{2 \times \lambda_g}{\pi \times B + d_f} \times \ln\left(\frac{\pi \times B}{d_f} + 1\right)$$

- If $d_f > B$ (well-insulated floors),

$$U_{fg;sog;0} = \frac{\lambda_g}{0.457 \times B + d_f}$$

The effect of the edge insulation is treated as a linear thermal transmittance, $\psi_{g;ed}$, which is obtained in two different ways, depending on if we have horizontal or vertical edge insulation.

It is considered an additional equivalent thickness resulting from the edge insulation, *d'*, defined as:

$$d' = R' \times \lambda$$

where *R'* is the additional thermal resistance introduced by the edge insulation (or foundation), calculated as:

$$R' = R_n - \frac{d_n}{\lambda}$$

With:

- R_n is the thermal resistance of the horizontal or vertical edge insulation (m²K/W);
- d_n is the thickness of the edge insulation (m).

For steady-state calculations, the effect of the edge insulation has been incorporated into the thermal transmittance of the floor with the following formulae:

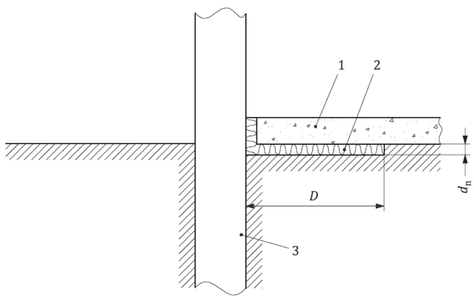
$$U_{fg;sog} = U_{fg;sog;0} + \frac{2 \times \psi_{g;ed}}{B}$$

For horizontal edge insulation, $\psi_{g;ed}$ is calculated based on the following formulae:

$$\psi_{g;ed} = -\frac{\lambda}{\pi} \times \left[\ln\left(\frac{D}{d_f} + 1\right) - \ln\left(\frac{D}{d_f + d'} + 1\right)\right] \quad \left[\frac{W}{mK}\right]$$

Where:

- *D* is the width of horizontal edge insulation (m).



Key
1 floor slab
2 horizontal edge insulation
3 foundation wall
d_n thickness of the edge insulation (or foundation)
D width of horizontal edge insulation

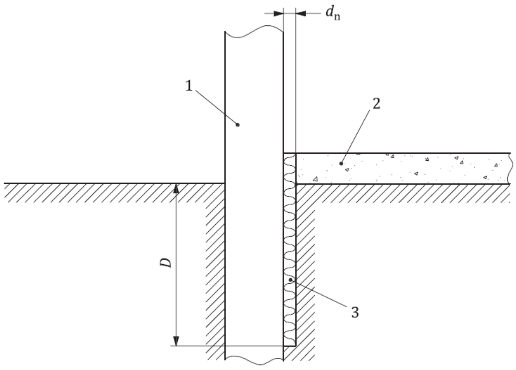
Figure 4.129_ Schematic diagram of horizontal edge insulation. Credits: EN ISO 13370:2017 (D)

For vertical edge insulation below ground along the perimeter of the floor, $\psi_{w;f}$ is calculated as:

$$\psi_{w;f} = -\frac{\lambda}{\pi} \times \left[\ln\left(\frac{2 \times D}{d_f} + 1\right) - \ln\left(\frac{2 \times D}{d_f + d'} + 1\right)\right] \qquad \left[\frac{W}{mK}\right]$$

Where:

- *D* is the depth of vertical edge insulation below ground level (m).



Key
1 foundation wall
2 floor slab
3 vertical edge insulation
d_n thickness of the edge insulation (or foundation)
D depth of vertical edge insulation (or foundation) below ground level

Figure 4.130_ Vertical edge insulation (insulation layer).
Credits: EN ISO 13370:2017 (D)

All the above formulas are contained in the script and therefore leave a choice according to the type of insulation used (technical specifications, thickness ...) and its positioning (vertical or horizontal).

Again, the results are then exported to the reference Excel file very quickly.

CV06 - EASEE Panel		
SLAB ON GROUND		
A Horizontal Projected Basement Area	493.08	m^2
P Building Basement Perimeter	153.40	m
$d_{w;e}$ Full Thickness of Perimetral Wall	0.49	m
R_{TOT} Floor Thermal Transmittance	2.89	m^2K/W
λ_g Ground Thermal Conductivity	2.00	W/m K
d_f	6.27	m
B Characteristic Dimension of Floor	6.43	m
$R_{g;eff}$ Thermal Resistance of the Ground	1.47	m^2K/W
$U_{f;sog}0$	0.22	W/m^2K
A*U	107.31	W/K
	ISO 13370:2017(E) Cap 7.1	

SLAB ON GROUND WITH EDGE INSULATION					
Perimetral (HORIZONTAL/VERTICAL) Insulation	VERTICAL		$\psi_{g;ed}$	NOT NEEDED	W/mK
D Insulation Deepness	0.70	m			
d_n Insulation Thickness	0.10	m			
λ Insulation Thermal Conductivity	0.04	W/mK			
$U_{f;sog}$	0.22	W/m^2K			
A*U	107.31	W/K			
R' Additional Thermal Resistance from Insulation	2.33	m^2K/W			
d' Additional Equivalent Thickness from Insulation	4.66	m			
ψ_{wf}	-0.05	W/mK			
H_g	99.40	W/K			
	ISO 13370:2017(E) annex D				

Table 4.12_ Hg calculation for EASEE configuration

Final calculation of H’t

After calculating H_D e H_g, we can finally calculate the global average heat transfer coefficient H’t:

$$H'_t = \frac{H_D + H_g}{\Sigma_K \times A_K}$$

In another document of the reference Excel file (8_“Building”) all the data to calculate H’t and evaluate its result are grouped.

As previously mentioned, our case study is located in Milan which is located in climate zone E.

Based on the type of intervention we are doing, we are able to obtain $\frac{S_{ren}}{S_{TOT}}$ and $\frac{S}{V}$ which allows us to obtain $H't_{limit}$:

DIMENSIONS		
Gross Total Volume	16936.13	m^3
Net Total Volume	16089.32	m^3
Gross Heated Volume	16936.13	m^3
Net Heated Volume	16089.32	m^3

Climate Zone
E

Legend:	
	Value to insert from Gh

Gross Total Envelope Surface	5805.53	m^2				
TYPE OF RENOVATION	CV04 - TES WOOD PANEL		CV06 - EASEE Panel		CV02 - BASE CASE + INSULATION	
Gross Envelope Surface under Renovation	4410.92	m^2	4410.92	m^2	4422.88	m^2
.. "Without Upper Floor"*	3615.13	m^2	3615.13	m^2	3627.09	m^2
S_{ren}/S_{TOT}	0.76	-	0.76	-	0.76	-
S/V	0.26	1/m	0.26	1/m	0.26	1/m
S_{wf}/V	0.21	1/m	0.21	1/m	0.21	1/m

N°	SHAPE RATIO (S/V)			A	B	C	D	E	F
1		S/V ≥	0.7	0.58	0.58	0.55	0.53	0.5	0.48
2	0.4	≤ S/V <	0.7	0.63	0.63	0.6	0.58	0.55	0.53
3		S/V <	0.4	0.8	0.8	0.8	0.8	0.75	0.7
	TYPE OF INTERVENTION								
4	Major second level extension and renovations for all building types			0.73	0.73	0.7	0.68	0.65	0.62

$$H't_{limit} = 0.75$$

Below is the calculation of H’t:

	CV04 - TES WOOD PANEL	Area [m^2]	CV06 - EASEE Panel	Area [m^2]	CV02 - BASE CASE + INSULATION	Area [m^2]
H_D [W/K]	2994.57	5312.45	3109.82	5312.45	2957.13	5312.45
H_g [W/K]	98.52	493.08	99.40	493.08	100.24	493.08
H'_T [W/m^2K]	0.53	[W/m^2K]	0.55	[W/m^2K]	0.53	[W/m^2K]
	3093.09	[W/K]	3209.22	[W/K]	3057.37	[W/K]
	OK		OK		OK	

→

CV04 - TES WOOD PANEL	CV06 - EASEE Panel	CV02 - BASE CASE + INSULATION	
Upper Limit	Upper Limit	Upper Limit	
0.75	0.75	0.75	[W/m^2K]
4354.15	4354.15	4354.15	[W/K]
IMPORTANT REQUALIFICATION I° LEVEL	IMPORTANT REQUALIFICATION I° LEVEL	IMPORTANT REQUALIFICATION I° LEVEL	

Table 4.13_ H't results

We can notice that all the 3 tested configurations respect the maximum limit of H't.

The results, as expected, are influenced by the thermal transmittance values of the various configurations and by the linear thermal bridges present.

We can see how the **TES and ETICS configurations are the best performing with a value of 0.53 W/m²K**.

Although it can be thought that the ETICS configuration was the best (in terms of dispersions), since the insulation is continuous along the entire facade, the thermal transmittance of this configuration (0.21 W/m²K) is greater than that of the TES solutions and EASEE (0.19 W/m²K). This has an impact on large surfaces. This concept can be verified in the tables concerning the H_D (*Table 4.10*) where it is noted that A*U of the "Perimetral Walls" is greater in the ETICS system.

However, a **big contribution** is made **by the linear thermal bridges**:

- As expected, the EASEE solution has the greatest lengths of linear thermal bridges, due to the many smaller panels compared to the TES solution. This is visible in the following tables at the element "Middle L.T.B.|Building|V" (vertical node between two panels), in which the EASEE solution has a total length of approximately 1,736 m compared to approximately 200 m of the TES solution. Similarly, under the item "Middle L.T.B.|Staircase|V", the first solution has a thermal bridge length of about 342 m, against 0 m of the TES solution (since the panels are large enough to reach the edges of the building).
- The ETICS system is the one with the least linear dispersions, thanks to the continuous external insulation that minimizes these coefficients. In this case, both the "Middle L.T.B|Building|V" and "Middle L.T.B.|Staircase|V" items have lengths equal to 0 m. For the same reason just explained, this configuration is able to have lower psi values than the other solutions, as can be seen in the items "Roof|Building|H", "Middle L.T.B.|Building|H", "Middle L.T.B.|Int.Overhang|H", etc.
  The average total transmittance of the wall ($U_{averageTOT}$=0.26 W/m^{2}K), in fact, is the one that differs less than the transmittance of the simple wall layers alone ($U_{wallETICS}$=0.21 W/m^{2}K).
- Finally, the TES solution, having shorter lengths of linear thermal bridges, is able to have an average wall thermal transmittance ($U_{averageTOT}$=0.26 W/m^{2}K) lower than that of the EASEE (0.30 W/m^{2}K). An interesting note is that the "Middle L.T.B.|Building|H" element has a greater dispersion than that of the other prefabricated configuration; this means that this system is more sensitive to heat losses in the inter-floors.

TES WOOD PANEL		
Elements	Tot. Linear T.B. [m]	Tot. ψ*l [W/K]
Roof|Staircase|H	24.30	4.04
Roof|Building|H	101.06	14.40
Middle L.T.B.|Staircase|V	0.00	0.00
Corner Staircase/Building |V	95.34	10.02
Corner Staircase |V	95.34	3.25
Middle L.T.B.|Building|V	200.87	10.54
Corner ETICS/Panel |V	294.00	27.00
Corner Panel/Panel |V	53.34	1.58
Windows|Staircase|V	39.37	5.71
Windows|Building|V	356.76	21.62
Middle L.T.B.|Staircase|H	170.10	9.16
Middle L.T.B.|Building|H	698.54	48.96
Middle L.T.B.|Ext. Overhang|H	55.20	1.48
Middle L.T.B.|Int. Overhang|H	91.80	30.56
Windows|Staircase UP|H	29.78	2.44
Windows|Staircase DOWN|H	29.78	2.35
Windows|Building UP|H	249.76	20.38
Windows|Building DOWN|H	249.76	-8.69
Basement|Staircase|H	170.10	76.02
Basement|Building|H	129.50	-9.07
Tot. Results	3810.62	271.74

EASEE PANEL		
Elements	Tot. Linear T.B. [m]	Tot. ψ*l [W/K]
Roof|Staircase|H	24.30	5.92
Roof|Building|H	101.06	20.42
Middle L.T.B.|Staircase|V	341.99	23.49
Corner Staircase/Building |V	95.34	9.28
Corner Staircase |V	95.34	0.26
Middle L.T.B.|Building|V	1736.11	72.74
Corner ETICS/Panel |V	294.00	27.29
Corner Panel/Panel |V	53.34	0.89
Windows|Staircase|V	39.37	8.10
Windows|Building|V	356.76	30.97
Middle L.T.B.|Staircase|H	170.10	6.53
Middle L.T.B.|Building|H	678.55	32.88
Middle L.T.B.|Ext. Overhang|H	63.14	1.17
Middle L.T.B.|Int. Overhang|H	83.86	26.56
Windows|Staircase UP|H	29.78	3.20
Windows|Staircase DOWN|H	29.78	3.30
Windows|Building UP|H	249.76	26.16
Windows|Building DOWN|H	249.76	11.02
Basement|Staircase|H	170.10	77.50
Basement|Building|H	129.50	-5.80
Tot. Results	5679.93	381.88

ETICS SYSTEM		
Elements	Tot. Linear T.B. [m]	Tot. ψ*l [W/K]
Roof|Staircase|H	24.10	2.45
Roof|Building|H	100.36	10.17
Middle L.T.B.|Staircase|V	0.00	0.00
Corner Staircase/Building |V	95.34	3.42
Corner Staircase |V	95.34	-5.45
Middle L.T.B.|Building|V	0.00	0.00
Corner ETICS/Panel |V	294.00	-6.42
Corner Panel/Panel |V	53.34	-1.17
Windows|Staircase|V	39.37	4.74
Windows|Building|V	356.76	18.36
Middle L.T.B.|Staircase|H	168.70	1.45
Middle L.T.B.|Building|H	638.36	19.73
Middle L.T.B.|Ext. Overhang|H	64.10	-3.02
Middle L.T.B.|Int. Overhang|H	82.90	16.89
Windows|Staircase UP|H	29.78	2.73
Windows|Staircase DOWN|H	29.78	2.54
Windows|Building UP|H	249.76	25.22
Windows|Building DOWN|H	249.76	6.48
Basement|Staircase|H	168.70	77.59
Basement|Building|H	129.30	-6.45
Tot. Results	3564.91	169.26

Table 4.14_ Linear thermal bridges for each retrofit solution.

Time (4D) and Cost (5D)

CHAPTER'S SUMMARY:

Although these are not the main topics of the thesis, **their development was carried out to integrate aspects beyond the third dimension, in a holistic approach that also integrates durations (4D) and economic issues (5D).** From the final graphs we can see how the ETICS solution is the most economical of all and how in it the largest percentage is covered by Labor. In the EASEE/TES panels, on the other hand, the largest percentage is made up of Materials and the total costs are significantly higher (about 50 €/m^2) than in ETICS.

Let's now turn to the topic of Time and Cost Management.

In fact, the geometric and performance aspects described so far, do not allow to analyze the entire procedure except with many limitations, failing to describe all the various aspects that characterize a building project. If by *Duration* we, therefore, mean a "period of time occupied or required by the performance of an event" [78] when we talk about *Costs* we will allude to the "expense necessary to obtain the availability of something" [78], where the subjects are always to be addressed in the building product.

Starting from the three types of solutions adopted, for the following analyzes we used the Regional Price List of public works for the Lombardy Region [79], the Schedule of civil/building works [80], the Operational Descriptions of the different manufacturing processes and all the online documentation useful for filling gaps in terms of quantities, unit prices and processing times.

If no major problems have emerged for the ETICS system in finding reference values (standard system with known information), the same cannot be said for the EASEE and TES prefabricated panels where the continuous design push (they are relatively recent solutions) has determined a strong scarcity of cost items for the entire process. As we mentioned in the very first lines of this chapter, however, **the values of Times and Costs thus obtained do not want to constitute a detailed analysis in themselves, but rather introduce terms of comparison that can give indications to the designers in the pre-design phase.**

As regards the item relating to the **Materials** chapter, it is not possible to describe every single step carried out for the different configurations, thus we strongly recommend reading the specific sheets that follow. However, the process followed was based on the attribution of a quantity value (expressed according to the most appropriate units of measurement from case to case) and a unit cost obtained from the price list, dimensionally consistent with the previous term.

CME_ETICS SYSTEM							
MATERIALS							
Code	Material Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit
MC.10.600.0020	Adesivo a base di cemento e dispersioni sintetiche esente da solventi.	6	Yield Kg/m^2	1.19	€/kg	7.14	€/m^2
MC.10.600.0050	Tasselli per fissaggio meccanico.	3	cad/m^2	0.54	€/cad	1.62	€/m^2
MC.10.300.0030	Pannello rigido in lana di roccia con resine termoindurenti, per isolamento termico dall'esterno di pareti con sistema a cappotto, conduttività termica W/mK 0,040, conforme alla norma UNI EN 13162, reazione al fuoco in Euroclasse A1, con marcatura CE;	120	mm	1.58	€/cm	18.95	€/m^2
-	Collante-Rasante a base cementizia grigio (AB57 Fassa Bortolo)	4.5	Yield Kg/m^2	14.95	€/25Kg	2.69	€/m^2
MC.10.600.0060	Rete in fibra di vetro					1.98	€/m^2
MC.10.600.0070	Profili di partenza, arrivo e chiusura laterale in alluminio del pannello isolante di facciata.	0.09	m/m^2	11.21	€/m	0.95	€/m^2
MC.10.600.0080	Angoli in alluminio per pannello isolante di facciata.	0.06	m/m^2	11.72	€/m	0.68	€/m^2
		MATERIALS Total Cost				***34.01***	***€/m^2***

Figure 4.131_ Materials - ETICS System

For **Labor**, however, a different approach was followed.

The first step was to determine the total number of operational teams that contributed to the construction of the element. Initially, the possibility that a single team could carry out the entire intervention by itself was evaluated; considerations have emerged that we consider important to report. By adopting an **ETICS** typology and for a building of this size, the estimated intervention times amounted to approximately 250 days. Moreover, it is unlikely to think that a single team of three workers can carry out the entire operation alone and for this reason, the number of **teams has been raised to two**. For prefabricated panels from **EASEE** and **TES**, if we exclude the workers driving the vehicles on the ground, this option turned out to be the best. On the one hand, the speed of realization still allows keeping the timing of realization contained, while, on the other hand, the difficulty of managing clutter and overcrowding of people and vehicles certainly does not encourage the management of the greater risks involved. The hourly cost for each operator was deducted from the price list based on the qualification, already inclusive of the items *General Costs* (approximately 14%) and *Company Profits* (10%).

On the other hand, particular attention must be paid to the calculation of durations (**Time**), which has been divided into two slightly different procedures depending on whether it was either ETICS or EASEE/TES. Both procedures, however, are based on what has been said above, which means the choice of setting up the operational team composed of a single unit (3 workers) for reasons of mutual comparison between different solutions have been considered.

For the **ETICS** it was decided to rely on an **hourly estimate per square meter of façade**, a process consistent with the system's assembly logic; for this reason, a value was determined starting from an hourly entry in h/m^2, which multiplied by the total square meters of facade, provided a value in hours of the entire intervention.

For **prefabricated panels**, on the other hand, where it made **no sense to refer to a generic square meter of surface, we referred to h/panel values inclusive of all the related works for correct installation**; these values were then multiplied by the total number of panels of that configuration to find the total durations in hours of intervention. This led to a balance between the installation times of the EASEE systems (assumed to be *30 minutes per panel*) and those of the TES panels (assumed to be *60 minutes per panel*).

COST OF LABOR							
Code	**Definition**	**Quantity**	**Unit**	**Cost**	**Unit**	**Unit Cost**	**Unit**
	Total Work Team	**2**					
TE.10.60.10	x1 - 3° level Worker (MA.00.005.0005)	0.02	h/m^2	37.08	€/h	1.48	€/m^2
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	0.37	h/m^2	34.51	€/h	25.19	€/m^2
TE.10.60.10	x1 - 1° level Worker (MA.00.005.0015)	0.37	h/m^2	31.23	€/h	22.80	€/m^2
MA.00.000	CONSULTATION NOTES Labor prices includes General Costs (13.50%) and Business Profits (10.00%)	***LABOR Total Cost***				***49.47***	*€/m^2*
	Hours of work per day [h]	**Quantity**	**Unit**	**Duration**	**Unit**	**Duration**	**Unit**
Total Duration	***8***	***2681.69***	*m^2*	*0.37*	*Cent. h/m^2*	***61.18***	*gg*

COST OF LABOR							
Code	**Definition**	**Quantity**	**Unit**	**Cost**	**Unit**	**Unit Cost**	**Unit**
	Total Work Team	**1**					
TE.10.60.10	x1 - 3° level Worker (MA.00.005.0005)	0.04	h/panel	37.08	€/h	0.45	€/m^2
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	0.50	h/panel	34.51	€/h	5.25	€/m^2
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	0.50	h/panel	34.51	€/h	5.25	€/m^2
MA.00.000	CONSULTATION NOTES Labor prices includes General Costs (13.50%) and Business Profits (10.00%)	***LABOR Total Cost***				***10.95***	*€/m^2*
	Hours of work per day [h]	**Quantity**	**Unit**	**Duration**	**Unit**	**Duration**	**Unit**
Total Duration	***8***	***2669.73***	*m^2*	*406.00*	*h*	***50.75***	*gg*

Figure 4.132_ Cost of Labour and Duration - ETICS + EASEE

The total days of intervention (days), **referred to the panels only**, were deducted by dividing the values obtained above (in h) by the working hours of a typical day, considered equal to 8 hours.

This is followed by the analysis carried out on the **Rent, Machinery and Construction Equipment**, made by identifying the correct items to be entered (also by watching videos/procedures/etc found online). Unit costs (€/h) attributed to these have been obtained from price lists which, multiplied by the total duration of the intervention (h), returned the total cost of these items.

RENT, MACHINERY AND CONSTRUCTION EQUIPMENT							
Code	Machinery and Equipments Definition	Duration	Unit	Unit Cost	Unit	Rent and Transportation Cost	Unit
NC.10.350.0010.a	Nolo ponteggio in struttura metallica tubolare. Compresi: il trasporto, il montaggio, lo smontaggio, la messa a terra, i parapetti, i fermapiedi, gli ancoraggi, le segnalazioni e tutte le misure ed accorgimenti atti a garantire la sicurezza degli operai e pubblica. Esclusi i piani di lavoro e i paraschegge: per i primi 30 giorni consecutivi o frazione, compreso montaggio e smontaggio.	30.00	gg	8.42	€/m²	22579.83	€
NC.10.350.0010.b	per ogni successivo periodo di 30 giorni consecutivi o frazione.	31.2	gg	0.73	€/m²	2034.38	€
NC.10.350.0050.a	Nolo di paraschegge (mantovana), realizzato con tavole di abete oppure con adatti elementi in lamiera zincata, compresa la struttura di sostegno e quanto altro necessario, l'approntamento ed il disarmo a fine utilizzo: per i primi 30 giorni consecutivi o frazione, compreso montaggio e smontaggio.	30.0	gg	7.58	€/m²	20327.21	€
NC.10.350.0050.b	per ogni successivo periodo di 30 giorni consecutivi o frazione	31.2	gg	1.14	€/m²	3176.97	€
		Cost of the Scaffolding				17.94	€/m²
NC.10.100.0020	Nolo di argano ad azionamento elettrico, compreso operatore e consumo di energia elettrica: motore 3 HP	0.04	h/m²	33.09	€/h	1.21	€/m²
NC.10.250.0030.b	Nolo di impastatrice per malte con materiali speciali, quali granuli di gomma, resine poliuretaniche e simili: funzionante, senza operatore.	0.37	h/m²	14.61	€/h	5.33	€/m²
		RENT AND TRANSPORTATION Total Cost				***24.48***	*€/m²*

Figure 4.133_ Rent, Machinery and Construction Equipment - ETICS

The **Profits** as well as the **General Business Expenses** were therefore applied, which are usually considered to be around 24% overall (respectively about 14% and 10%). This percentage was applied only to the items of Materials and Rent/Transportation as we recall that the items of Labor from the price list already included this fraction.

Based on the **totals** thus identified, a sum was carried out to identify the unit prices of each solution per square meter of façade surface.

CME_ETICS SYSTEM			
TOTAL RAW MATERIALS		***107.97***	*€/m²*
% Materials		31.5	%
% Labor		45.8	%
% Rent/Transportation		22.7	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***122.01***	*€/m²*

Figure 4.134_ Final results - ETICS

The following pages show all the calculations carried out for the three analyzed configurations.

CME_ETICS SYSTEM

MATERIALS							
Code	Material Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit
MC.10.600.0020	Adesivo a base di cemento e dispersioni sintetiche esente da solventi.	6	Yield Kg/m²	1.19	€/kg	7.14	€/m²
MC.10.600.0050	Tasselli per fissaggio meccanico.	3	cad/m²	0.54	€/cad	1.62	€/m²
MC.10.300.0030	Pannello rigido in lana di roccia con resine termoindurenti, per isolamento termico dall'esterno di pareti con sistema a cappotto, conduttività termica W/mK 0,040, conforme alla norma UNI EN 13162, reazione al fuoco in Euroclasse A1, con marcatura CE;	120	mm	1.58	€/cm	18.95	€/m²
-	Collante-Rasante a base cementizia grigio (AB57 Fassa Bortolo)	4.5	Yield Kg/m²	14.95	€/25Kg	2.69	€/m²
MC.10.600.0060	Rete in fibra di vetro					1.98	€/m²
MC.10.600.0070	Profili di partenza, arrivo e chiusura laterale in alluminio del pannello isolante di facciata.	0.09	m/m²	11.21	€/m	0.95	€/m²
MC.10.600.0080	Angoli in alluminio per pannello isolante di facciata.	0.06	m/m²	11.72	€/m	0.68	€/m²
		MATERIALS Total Cost				***34.01***	***€/m²***

COST OF LABOR							
Code	Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit
	Total Work Team	**2**					
TE.10.60.10	x1 - 3° level Worker (MA.00.005.0005)	0.02	h/m²	37.08	€/h	1.48	€/m²
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	0.37	h/m²	34.51	€/h	25.19	€/m²
TE.10.60.10	x1 - 1° level Worker (MA.00.005.0015)	0.37	h/m²	31.23	€/h	22.80	€/m²
MA.00.000	CONSULTATION NOTES Labor prices includes General Costs (13.50%) and Business Profits (10.00%)	***LABOR Total Cost***				***49.47***	***€/m²***
	Hours of work per day [h]	**Quantity**	**Unit**	**Duration**	**Unit**	**Duration**	**Unit**
Total Duration	***8***	***2681.69***	*m²*	*0.37*	*Cent. h/m²*	***61.18***	*gg*

RENT, MACHINERY AND CONSTRUCTION EQUIPMENT							
Code	Machinery and Equipments Definition	Duration	Unit	Unit Cost	Unit	Rent and Transportation Cost	Unit
NC.10.350.0010.a	Nolo ponteggio in struttura metallica tubolare. Compresi: il trasporto, il montaggio, lo smontaggio, la messa a terra, i parapetti, i fermapiedi, gli ancoraggi, le segnalazioni e tutte le misure ed accorgimenti atti a garantire la sicurezza degli operai e pubblica. Esclusi i piani di lavoro e i paraschegge: per i primi 30 giorni consecutivi o frazione, compreso montaggio e smontaggio.	30.00	gg	8.42	€/m²	22579.83	€
NC.10.350.0010.b	per ogni successivo periodo di 30 giorni consecutivi o frazione.	31.2	gg	0.73	€/m²	2034.38	€
NC.10.350.0050.a	Nolo di paraschegge (mantovana), realizzato con tavole di abete oppure con adatti elementi in lamiera zincata, compresa la struttura di sostegno e quanto altro necessario, l'approntamento ed il disarmo a fine utilizzo: per i primi 30 giorni consecutivi o frazione, compreso montaggio e smontaggio.	30.0	gg	7.58	€/m²	20327.21	€
NC.10.350.0050.b	per ogni successivo periodo di 30 giorni consecutivi o frazione	31.2	gg	1.14	€/m²	3176.97	€
		Cost of the Scaffolding				**17.94**	€/m²
NC.10.100.0020	Nolo di argano ad azionamento elettrico, compreso operatore e consumo di energia elettrica: motore 3 HP	0.04	h/m²	33.09	€/h	1.21	€/m²
NC.10.250.0030.b	Nolo di impastatrice per malte con materiali speciali, quali granuli di gomma, resine poliuretaniche e simili: funzionante, senza operatore.	0.37	h/m²	14.61	€/h	5.33	€/m²
		RENT AND TRANSPORTATION Total Cost				***24.48***	***€/m²***

CME_ETICS SYSTEM			
TOTAL RAW MATERIALS		***107.97***	*€/m²*
% Materials		31.5	%
% Labor		45.8	%
% Rent/Transportation		22.7	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***122.01***	*€/m²*

CME_EASEE SYSTEM

MATERIALS

Code	Material Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit
MC.03.360.0030	CALCESTRUZZO + Rete in fibra di carbonio, grammatura 200 g/mq, maglia 10 x 10 mm, modulo elastico 252±2% GPa, resistenza a trazione 260 kN/m	12.5	mm	2745.2	€/m3	34.32	€/m2
MC.10.300.0020.d	Lastre in polistirene espanso sinterizzato, prodotte con materie prime vergini esenti da rigenerato; reazione al fuoco Euroclasse E; conformi alla norma UNI EN 13163, con marcatura CE; nelle Classi e spessori: Classe 120 RF - bordi diritti, per ogni 10 mm in più	140	mm	1.01	€/cm	14.14	€/m2
MC.03.360.0030	CALCESTRUZZO + Rete in fibra di carbonio, grammatura 200 g/mq, maglia 10 x 10 mm, modulo elastico 252±2% GPa, resistenza a trazione 260 kN/m	12.5	mm	2745.2	€/m2	34.32	€/m2
-	Fondo giunto in polietilene espanso a celle chiuse per cavità fra panlli contigui	1.67	m/m2	0.35	€/m	0.58	€/m2
1C.06.580.0020	Fissaggio chimico di barre filettate con estremità a doppio taglio simmetrico a 45° con dado e rosetta, in acciaio con classe di resistenza 5.8 secondo ISO 898-1:2013, zincato a freddo, realizzato con ancorante chimico predosato in fiala, marcato CE per applicazioni in calcestruzzo fessurato e per Categoria di Prestazione Sismica C1.	1.00	cad/m2	1.36	€/cad	1.36	€/m2
		MATERIALS Total Cost				***84.71***	***€/m²***

COST OF LABOR

Code	Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit
	Total Work Team	**1**					
TE.10.60.10	x1 - 3° level Worker (MA.00.005.0005)	0.04	h/panel	37.08	€/h	0.45	€/m²
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	0.50	h/panel	34.51	€/h	5.25	€/m²
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	0.50	h/panel	34.51	€/h	5.25	€/m²
MA.00.000	CONSULTATION NOTES Labor prices includes General Costs (13.50%) and Business Profits (10.00%)	***LABOR Total Cost***				***10.95***	***€/m²***

	Hours of work per day [h]	Quantity	Unit	Duration	Unit	Duration	Unit
Total Duration	***8***	***2669.73***	*m²*	*406.00*	*h*	***50.75***	*gg*

RENT, MACHINERY AND CONSTRUCTION EQUIPMENT

Code	Machinery and Equipments Definition	Duration	Unit	Unit Cost	Unit	Rent and Transportation Cost	Unit
NC.10.200.0030	Nolo autoscala, altezza fino a 28 m, compreso autista addetto alla manovra (durata minima del nolo 8 ore)	0.50	h/panel	58.56	€/h	8.91	€/m²
NC.10.200.0040	Nolo autogrù telescopica, compreso l'addetto alla manovra, carburante e lubrificante (durata minima del nolo 4 ore): portata 25 t, braccio telescopico 22 m	0.50	h/panel	93.81	€/h	14.27	€/m2
NC.10.050.0010	Nolo automezzo compreso autista, carburante e lubrificanti, anche ribaltabile: portata utile 5.0 t	0.50	h/panel	50.42	€/h	7.67	€/m2
		RENT AND TRANSPORTATION Total Cost				***30.84***	***€/m²***

CME_EASEE SYSTEM

TOTAL RAW MATERIALS		***126.50***	***€/m²***
	% Materials	67.0	%
	% Labor	8.7	%
	% Rent/Transportation	24.4	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***154.23***	***€/m²***

CME_TES SYSTEM

MATERIALS

Code	Material Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit	Quantity	Unit	Unit Cost	Unit
MC.02.010.0050	Morali e mezzi morali in abete (Coupling Beam)	2400	mm^2	349.58	€/m^3	0.84	€/m	0.38	m/m^2	0.32	€/m^2
MC.02.010.0050	Morali e mezzi morali in abete (Giunzioni M-F)	4000	mm^2	349.58	€/m^3	1.40	€/m	0.38	m/m^2	0.54	€/m^2
MC.02.010.0050	Morali e mezzi morali in abete (Montanti-Traversi)	4800	mm^2	349.58	€/m^3	1.68	€/m	9.00	m/m^2	15.10	€/m^2
MC.02.010.0050	Morali e mezzi morali in abete (Cavità ventilata)	1728	mm^2	349.58	€/m^3	0.60	€/m	10.00	m/m^2	6.04	€/m^2
-	Guarnizione EPDM (monomero di etilene-propilene-diene)					2.81	€/m	0.33	m/m^2	0.94	€/m^2
-	Pannello OSB 4, spessore 24 mm	2	pz.	27.50	€/m^2	55.00	€/m^2				
MC.10.300.0030	Pannello rigido in lana di roccia con resine termoindurenti, per isolamento termico dall'esterno di pareti con sistema a cappotto, conduttività termica W/mK 0,040, conforme alla norma UNI EN 13162, reazione al fuoco in Euroclasse A1, con marcatura CE;	120	mm	1.58	€/cm	18.95	€/m^2				
-	Rivestimento con pannelli lignei, dim 1000x3000x6 mm					42.50	€/m^2				
-	Viti in acciaio al carbonio, testa svasata con tassello in plastica per calcestruzzo non fessurato, Certificazioni/Risultati dei test: ETA	5.00	cad/m^2	1.10	€/cad	5.50	€/m^2				
		MATERIALS Total Cost				***144.89***	*€/m^2*				

COST OF LABOR

Code	Definition	Quantity	Unit	Cost	Unit	Unit Cost	Unit
	Total Work Team	**1**					
TE.10.60.10	x1 - 3° level Worker (MA.00.005.0005)	0.04	h/panel	37.08	€/h	0.11	€/m^2
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	1.00	h/panel	34.51	€/h	2.57	€/m^2
TE.10.60.10	x1 - 2° level Worker (MA.00.005.0010)	1.00	h/panel	34.51	€/h	2.57	€/m^2
MA.00.000	CONSULTATION NOTES Labor prices includes General Costs (13.50%) and Business Profits (10.00%)	***LABOR Total Cost***				***5.26***	*€/m^2*

	Hours of work per day [h]	Quantity	Unit	Duration	Unit	Duration	Unit
Total Duration	***8***	***2669.73***	*m^2*	*199.00*	*h*	***24.88***	*gg*

RENT, MACHINERY AND CONSTRUCTION EQUIPMENT

Code	Machinery and Equipments Definition	Duration	Unit	Unit Cost	Unit	Rent and Transportation Cost	Unit
NC.10.200.0030	Nolo autoscala, altezza fino a 28 m, compreso autista addetto alla manovra (durata minima del nolo 8 ore)	1.00	h/panel	58.56	€/h	4.37	€/m^2
NC.10.200.0040	Nolo autogrù telescopica, compreso l'addetto alla manovra, carburante e lubrificante (durata minima del nolo 4 ore): portata 25 t, braccio telescopico 22 m	1.00	h/panel	93.81	€/h	6.99	€/m2
NC.10.050.0010	Nolo automezzo compreso autista, carburante e lubrificanti, anche ribaltabile: portata utile 5.0 t	1.00	h/panel	50.42	€/h	3.76	€/m2
		ENT AND TRANSPORTATION Total Cos				***15.12***	*€/m^2*

CME_TES SYSTEM

TOTAL RAW MATERIALS		***165.26***	*€/m^2*
	% Materials	87.7	%
	% Labor	3.2	%
	% Rent/Transportation	9.1	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***203.66***	*€/m^2*

Let's now move on to the comparison between the individual items.

For the type of **External Thermal Insulation Composite System** (ETICS), it immediately emerges how the costs are lower than the other solutions adopted, with an indicative saving of about 30 €/m² respect the EASEE solution and 80 €/m² respect the TES one. A consideration to be made concerns the hypothesis of setting the number of operational teams equal to one, two or three. It is evident that, along with the price, the duration of the intervention with few Work Teams has absolutely unacceptable values. If we increased the number of teams equal to two or three, we would see how the intervention days would drop significantly, along with the costs of the Rents which would decrease too. Another interesting consideration is certainly to note that in percentage the costs of materials have a lesser influence than those of labour, also proof of the fact that the system does not have great complexity in technology (which can be translated into contained costs of materials) while guaranteeing good insulation performance.

Moving on to the **EASEE** solution (Envelope Approach to improve Sustainability and Energy Efficiency), we see how while the costs per square meter are higher than those of traditional thermal insulation systems (*remember that this is an approximate but still indicative estimate*), installation and operating times are significantly reduced by about 5-6 times compared to traditional systems. This substantially reflects what we saw previously, that is, a strong reduction in timing thanks to a faster and more precise installation. At the same time, the costs of materials weigh much more in proportion to those of labour and rents, also a symptom of a greater value/effort than what is achieved in the industry compared to the construction site.

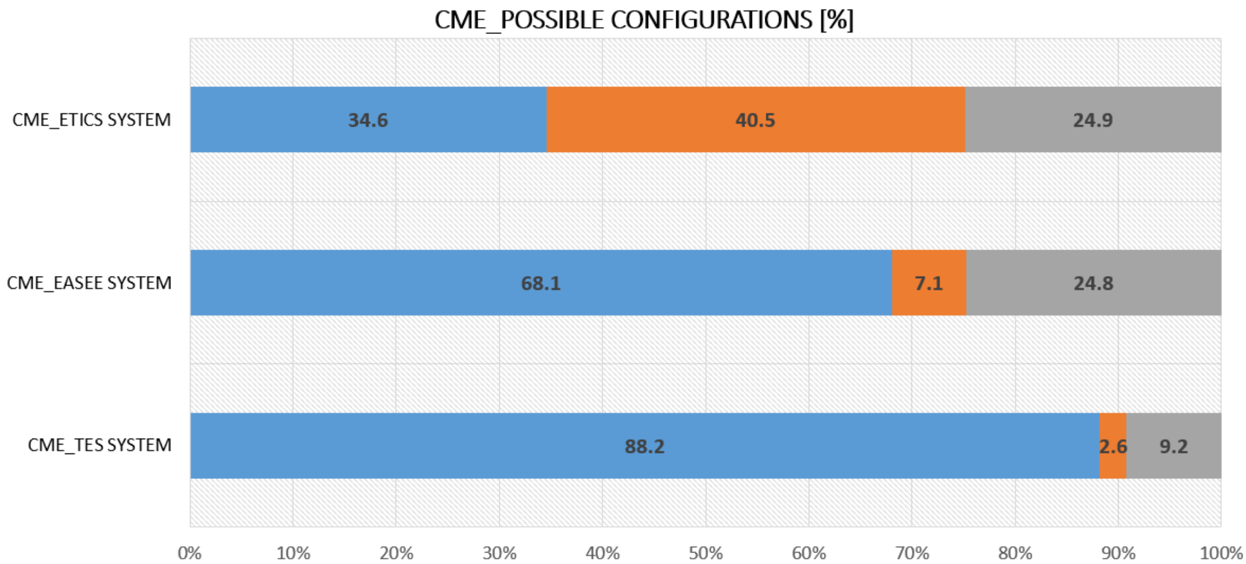
Similar considerations can be made for the **TES** solution, with the difference that although the unit assembly time of the single panel is greater than that of the EASEEs, the reduced number of resulting elements affects much more in the final bill in proportion; this translates into a shorter overall assembly time for both the ETICS and EASEE solution. As an indication, wooden materials were found to be particularly expensive (especially OSB panels) and therefore in% the Materials item is the most expensive of all, both with respect to Labor and Rent of the same TES and with respect to the materials item of the others. two solutions.

CME_ETICS SYSTEM			
TOTAL RAW MATERIALS		*107.97*	*€/m2*
% Materials		34.6	%
% Labor		40.5	%
% Rent/Transportation		24.9	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***122.01***	***€/m2***
Total Duration		***61.18***	***gg***
CME_EASEE SYSTEM			
TOTAL RAW MATERIALS		*126.50*	*€/m2*
% Materials		68.1	%
% Labor		7.1	%
% Rent/Transportation		24.8	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***154.23***	***€/m2***
Total Duration		***50.75***	***gg***
CME_TES SYSTEM			
TOTAL RAW MATERIALS		*165.26*	*€/m2*
% Materials		88.2	%
% Labor		2.6	%
% Rent/Transportation		9.2	%
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***203.66***	***€/m2***
Total Duration		***24.88***	***gg***

CME_ETICS SYSTEM			
TOTAL RAW MATERIALS		*107.97*	*€/m2*
Materials		42.2	€/m2
Labor		49.5	€/m2
Rent/Transportation		30.4	€/m2
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***122.01***	***€/m2***
Total Duration		***61.18***	***gg***
CME_EASEE SYSTEM			
TOTAL RAW MATERIALS		*126.50*	*€/m2*
Materials		105.0	€/m2
Labor		10.9	€/m2
Rent/Transportation		38.2	€/m2
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***154.23***	***€/m2***
Total Duration		***50.75***	***gg***
CME_TES SYSTEM			
TOTAL RAW MATERIALS		*165.26*	*€/m2*
Materials		179.7	€/m2
Labor		5.3	€/m2
Rent/Transportation		18.7	€/m2
Business Overheads and Various Charges	24.00%		
UNIT PRICE OF THE SOLUTION		***203.66***	***€/m2***
Total Duration		***24.88***	***gg***

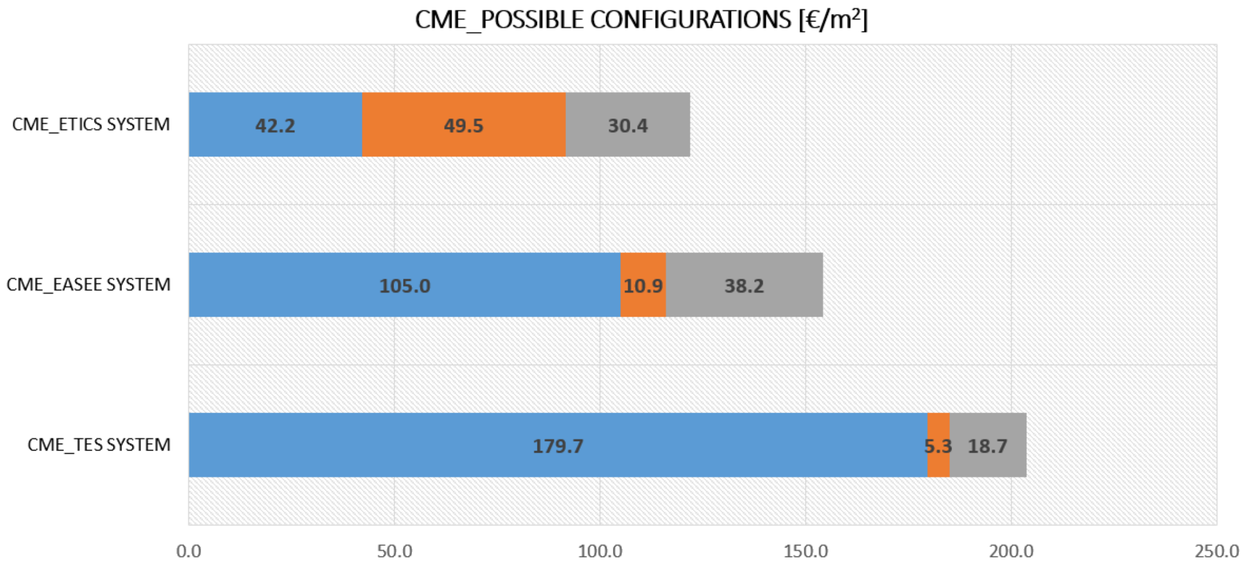
Table 4.15_ Data comparison in percentage (left), in €/m² (right).

The graphical representation of the tables shown above can be viewed on the following page.



	CME_TES SYSTEM	CME_EASEE SYSTEM	CME_ETICS SYSTEM
% Materials	88.2	68.1	34.6
% Labor	2.6	7.1	40.5
% Rent/Transportation	9.2	24.8	24.9

Figure 4.135_ Final Solution Comparisons (%).



	CME_TES SYSTEM	CME_EASEE SYSTEM	CME_ETICS SYSTEM
Materials	179.7	105.0	42.2
Labor	5.3	10.9	49.5
Rent/Transportation	18.7	38.2	30.4

Figure 4.136_ Final Solution Comparisons (€/m²).

Management (7D)

CHAPTER'S SUMMARY:

The world energy situation is already negative on the issue of the sustainability of current consumption; the population, however, is expected to grow and this could further aggravate the situation. For this reason, it was decided to resort to **Life Cycle Assessment** (LCA) analysis to help understand how to limit other damages and it is important that these are done in early-stage design. The results found clearly show how the type of TES panels presents the best value in terms of Renewable Primary Energy/Total Primary Energy.

The **global population** and the Level of Urbanization are **expected to grow at an alarming rate**, and by the end of the 21st century, it is estimated that it can fluctuate up to 11.2 billion [26], depending on the scenario considered. In addition, a significant **increase in the number of people living in cities** is also expected, with a corresponding increase in energy demand - cities are in fact responsible for around 70% of carbon emissions [81,82] - with a consequent increase in the consumption of resources (water, soil, etc.) and therefore of **environmental degradation**. There is therefore a growing interest and support to ensure that the development of the human species is sustainable for the planet Earth.

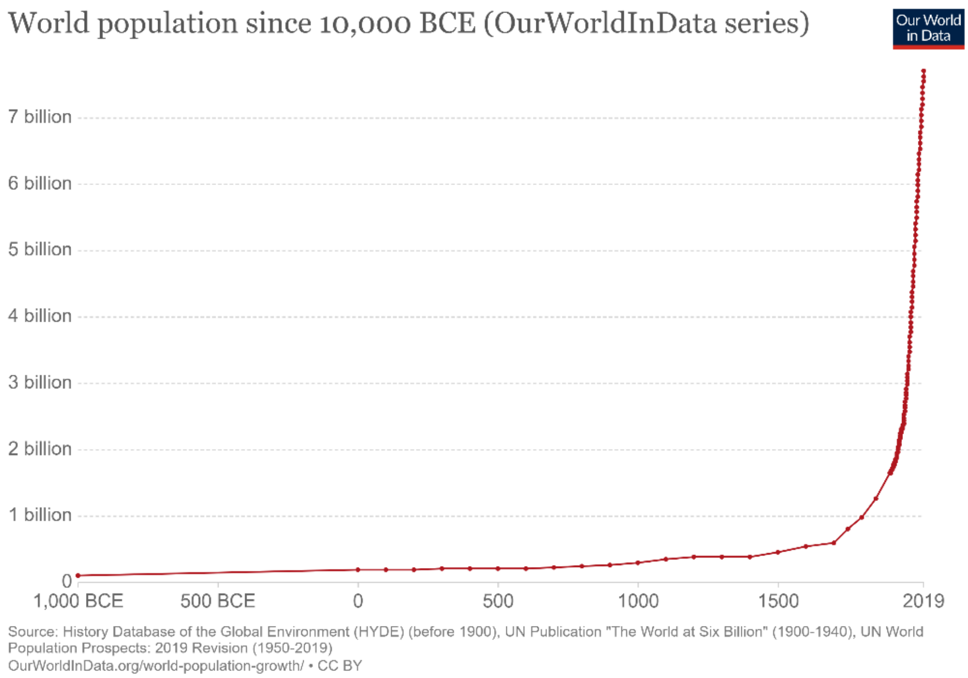


Figure 4.137_World population since 1,000 BCE - OurWorldInData

To analyze this phenomenon, we can refer to the **IPAT** equation [83] [84], which has the advantage of putting the main factors involved in a simplistic relationship of a quantity that by its nature is much more complex, thus providing an idea about the main dominant quantities:

Environmental Impact (I) = Population (P) x Affluence (A) x Technology (T)

While at the first term we find the resulting total environmental impact that the human population has on the Planet, at the second we have:

- **Population**: which, as previously mentioned, is a rapidly growing number, increasing the weight of the actions carried out on sustainability;
- **Affluence**: habits - and above all consumption habits - are one of the determining factors for determining the total environmental impact; it is not difficult to imagine that if consumption increases, the impact on the environment also increases. We usually determine this value with the GDP / person relationship, if internal production increases, in a certain way so does consumption; since this value (GDP) has grown considerably over the years (increase in general well-being, etc.), so has the impact on the environment;
- **Technology**: the level of technology of a certain country, as well as the previous ones, directly contributes to determining the degree of exploitation of resources (this includes the number and development of cars in possession, ...); how resource-intensive the production of affluence is; how much environmental impact is involved in creating, transporting and disposing of the goods, services and amenities used; improvements in terms of efficiency, therefore, make it possible to reduce the intensity of the impact and therefore the value of T.

According to future-oriented estimates, it is believed that by multiplying the first two terms of the equation there is an increase of about 4-8 times the current impact; to compensate for these further increases, also considering that already at the current level they present themselves as having a lot (too much?) impact, our goal is to counter-whiten with reductions elsewhere. The only possible solution would therefore be to be able to increase the overall efficiency of the system by about eight percentage points, but this is very difficult to achieve that much.

We, therefore, rely on tools, approaches, ... which also allow us to reduce the number of resources consumed; the **Life Cycle Assessment (LCA)** approach falls within this framework. But what is its definition? According to ISO 14040 [85]:

> *LCA is a technique [...] compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts associated with those inputs and outputs, and interpreting the results of the inventory and impact phases in relation to the objectives of the study.*

It, therefore, allows us to look upstream and downstream of a process, product, activity or service and all the consequences that may have a certain impact on the environment; it also quantifies the use of resources and emissions into the environment per unit of product or service provided, at each stage of the process, from the extraction of the material to its eventual disposal.

It generally consists of the development of the following four parts: definition of a goal, data analysis, impact assessment, interpretation of results; precisely for this reason it is extremely important to define a **reference system**, within whose boundaries to act. What is meant by the system? [82]

The system is defined as a group of dynamically interacting elements, organized to achieve one or more functions. It is identified by the elements it contains, called processes, the links between these elements and the boundaries that delineate it from its surroundings.

With reference to the impact assessment, the **crucial phases** of the LCA are [86] :

- A1-A3: production of materials
- A4: transport to the construction site
- B2: maintenance
- B4: replacement
- B6: energy consumption in use
- B7: water consumption in use
- C2: transport to disposal plants
- C3: waste treatment
- C4: disposal
- D: benefits and impacts beyond the system boundaries

and below the items considered for the purpose of our analysis will be indicated.

Even if the method has been widely accepted on a theoretical level, it hardly finds real practical application and when it does, it usually comes into play in the post-design phase - often to satisfy mandatory certifications at a regulatory level when it can no longer improve the environmental performance of the project [87].

In general terms, it is therefore good to remember that any **decisions taken in the early stages of the design process have the greatest influence** as they lay the foundations for subsequent choices [88].

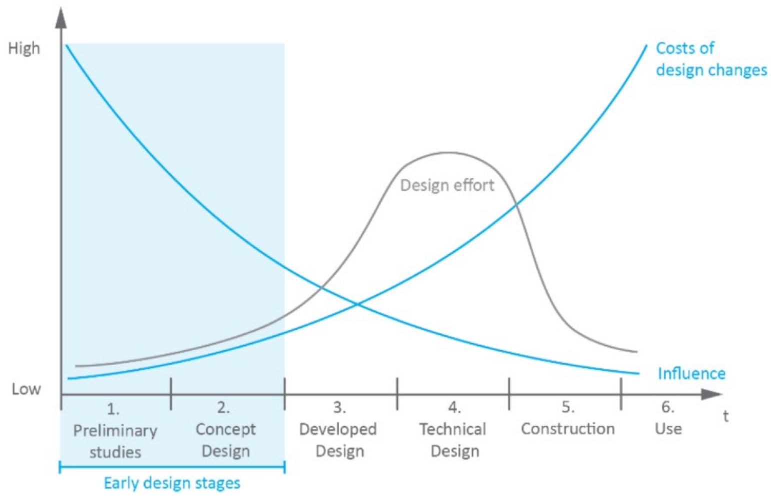


Figure 4.138_ Influence of the early design stages

This is equally true - if not more so - also with regard to the possibility of optimizing and reducing Green House Gas (GHG) emissions as well as for all the factors involved in the entire Life Cycle Assessment (LCA) process, which therefore requires to be applied in early design stages to allow holistic environmental optimization of the entire building [89].

It is with these objectives listed above that we then approached the Life Cycle Assessment analysis, wanting to **provide our Tool with an additional evaluator** on the impact of the solution adopted on the environment. It should be noted immediately that the analyzes listed below do not presume to represent a detailed and finite evaluation, but rather constitute a pre-design analysis; in fact, the aim is to have information that is as plausible as possible, useful for guiding the choice of projects towards one solution rather than the other. It is important to underline that the approach adopted has the advantage of reconciling the ease of calculation with the usefulness of having a comparison parameter, which can be implemented at any time with new, more careful and detailed analyzes. In this regard, it should be noted that, although the main steps of the tool we present have been performed on the **Grasshopper parametric modelling software**, it is possible to create live links with other programs (more commonly used and therefore more widespread) such as Excel. Although there was neither the opportunity nor the intention to deepen in this sense, on several occasions and fields of belonging we have had the opportunity to experience firsthand the strong interoperability with which it is possible to provide Input to Grasshopper via Excel or otherwise provide Output to Excel via Grasshopper. it is for this reason that we feel we can affirm with a certain level of confidence that any future developments are possible and applicable.

The tools currently available [90] [91] [92] [93] to carry out LCA analyzes, they were analyzed to try to understand the limits and possibilities of each, according to the set objectives; between these two they proved to be immediately valid for reaching an adequate compromise between simplicity of analysis, capacity for parametric development and reliability of the results, they are Tortuga and Bombyx.

Tortuga helps you to evaluate a simple GWP overview of your model and lets you compare different design options easily. You can choose between two different LCA Material databases which are directly accessible from Grasshopper (Quartz Project LCA Data (US/GaBi) and Ökobau.dat (DE)) or use your own materials using a csv table. Despite this, Tortuga is still in the beta stage, it is the first release, and it might contain still bugs, so no warranty is provided. That is the main reason why, despite the fact any .csv data could be imported (with precise standards of formatting), this plug-in has been excluded.

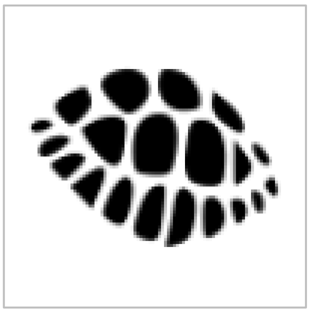


Figure 4.139_ Tortuga logo

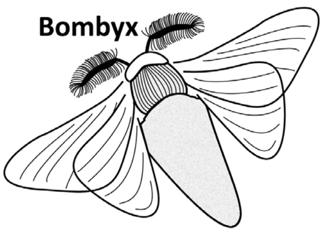


Figure 4.140_ Bombyx logo

The second software that has been studied is **Bombyx** which, just like the previous one, allows simplified analysis of entire components in terms of LCA during all the design phases. It stands out mainly for the reliability of the results and the degree of development achieved, which is certainly good. As a design team, we were even able to contact the developers *Saso Basic* and *Alina Galimshina - whom we sincerely thank for the time they spent with us* - and arrange a meeting with them on Zoom; on this occasion, we had the opportunity to clarify some fundamental aspects for the objectives of the Tool we are proposing. The main one concerns the choice of the reference library, which is an LCA dataset provided by the Swiss Conference of the Construction and Real Estate Organs of PublicBuilders (KBOB) [94] for typical building materials in Switzerland, and it is based on Ecoinvent, which however does not make its libraries available for free. This choice, although not fully truthful, can be considered acceptable for the case study analyzed, which we recall is located in the municipality of Monza (MI); depending on the circumstances, for projects located at a great distance from the Swiss borders, this statement may no longer be acceptable and therefore it is necessary to resort to the adoption of new libraries.

The **calculation** that the program performs can be schematized as [89] :

$$I_{LC} = I_O + I_E$$

With:

- I_{LC} : Life Cycle Impact;
- I_E : Embodied Impact resulting from production and the end of life of the building (modules A1-A3, C3 and C4). It is obtained from the following expression:

$$I_E = \sum_j \left(M_j \times IF_{E,j} \times \left(1 + R_j\right)\right)$$

Where M_j is the mass of each material obtained from the multiplication between the Volume (Areas per Thickness) and the density Value, imported from the KBOB database; IF_{Ej} is the specific Embodied Impact Factor of the material, still obtained from the KBOB library; R_j is the Number of Replacements, calculated as the ratio between Reference Study Period (RSP) and Reference Service Life (RSL) of the building component menus one:

$$R_j = \left[RSP/RSL_j\right] - 1$$

For the analysis RSP = 60 years and RSL = 20 years have been assumed.

- I_O : Operational Impact resulting from the operational energy use of the building (life cycle module B6 according to EN 15978). It is obtained from the following expression:

$$I_E = \sum_j \left(ED_i \times IF_{O,i}\right) \times RSP$$

It consists of the sum of all different kinds of operational Energy Demand during the use phase (Ed_i) with reference to one year of operation multiplied by the operational Impact Factor of the energy carrier ($IF_{o,i}$) and by the numbers of years of the Reference Study Period (RSP). The ED is calculated according to Swiss standards while the IF_o factor depends on the energy carrier employed and is taken from the KBOB database. This term has been neglected in order to focus on the Embodied Impact of the three different technological solutions.

The results can therefore be expressed as vectors, as follows:

$$IF_{E,j} = \begin{pmatrix} UBP \\ PEnr\ and\ PEr \\ GWP \end{pmatrix}$$

where:

- UBP: stand for "*Umweltbelastungspunkte*" or eco points, a single score indicator based on the Swiss Method of Ecological Scarcity.

- The primary energy demand is provided as renewable part (Per) and non-renewable part (PEnr).
- Global Warming Potential 100 (GWP) expressed in CO2- equivalent as an indicator for climate change is used as defined by IPCC [7].

For the purpose of the analysis, it was decided to **report** the fraction of Renewable Primary Energy (PERen) over the Total value (PETot), considering all the phases of GHG Embodied - Replacement - End of Life (kWh oil-eq). The results obtained clearly show that the trend is in clear favour of the TES Energy Facade solution, which is mainly made up of wooden material and from which it draws strong benefits in terms of sustainability (in this regard, see the related TES chapter).

In the screens that follow, we report the materials selected for each layer of the solutions analyzed.

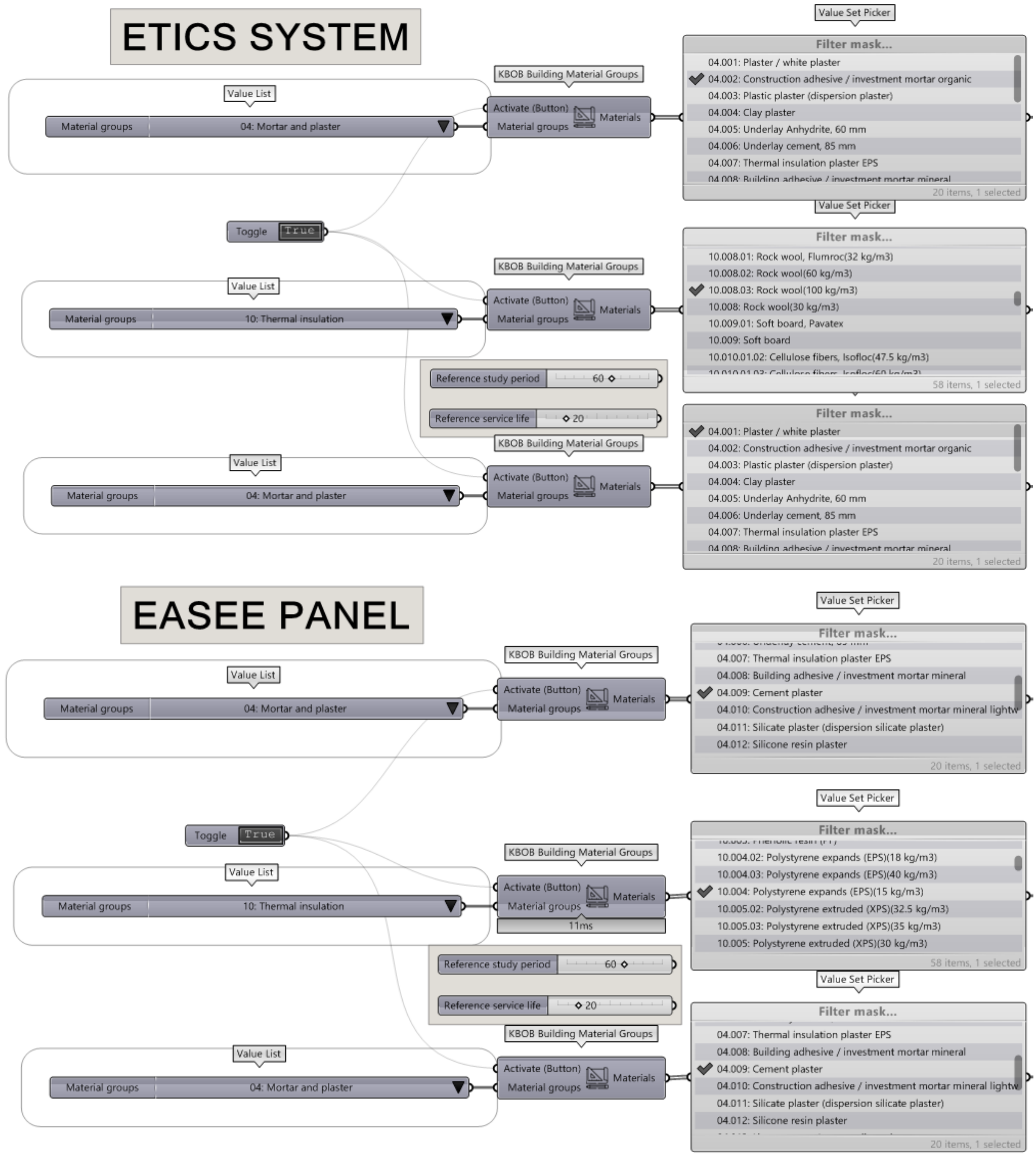


Figure 4.141_ Materials selected for LCA analysis - ETICS + EASEE.

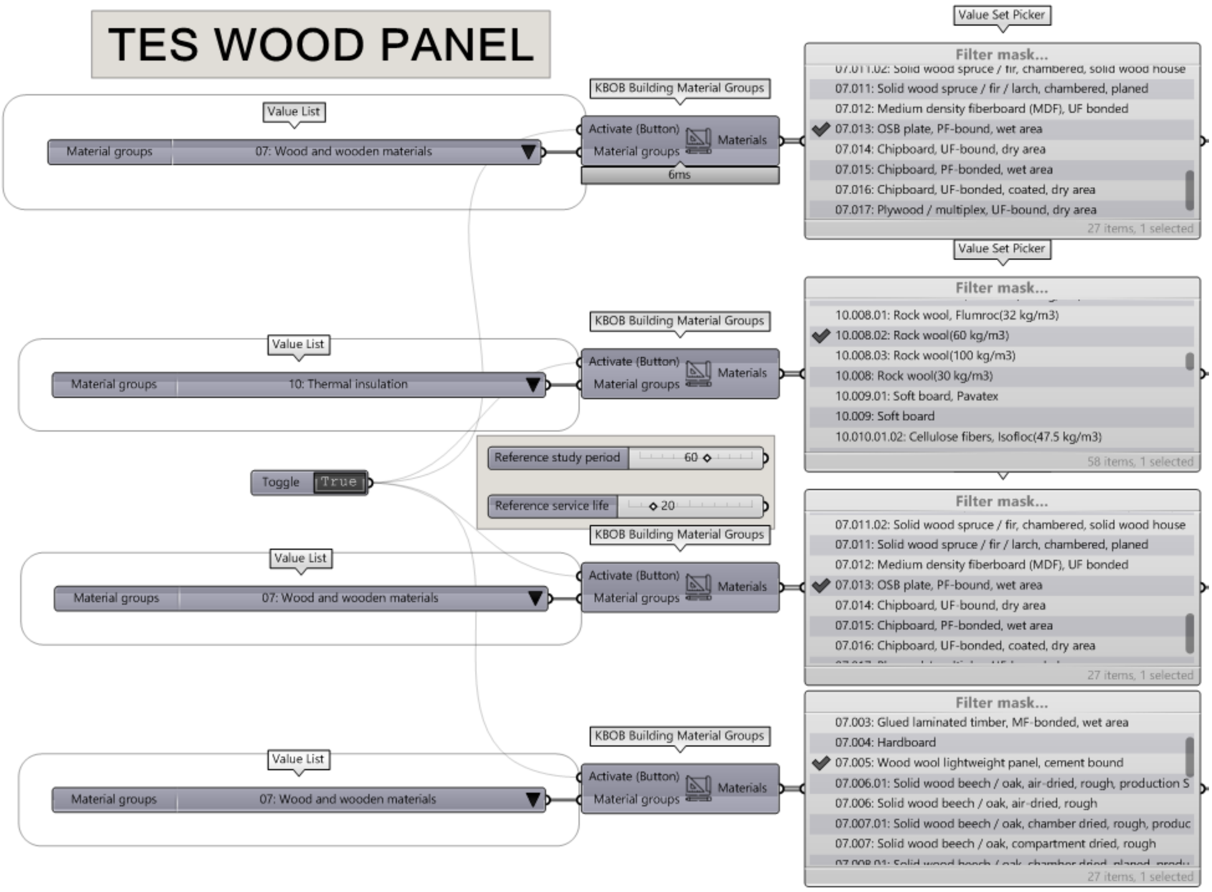


Figure 4.142_ Materials selected for LCA analysis - TES.

5. RESULTS & DISCUSSION

CHAPTER'S SUMMARY:

In this chapter we enter the heart of the usefulness of our tool. The results of our study are grouped in special diagrams and compared with each other. It also explains how the results of our analysis are exported to the open-source tool *Design Explorer* and *Revit*. In conclusion, a discussion is made on what we have learned, and the adaptability of our tool is tested on a building with a different geometry from the initial one.

Once we obtained the parameters that we had set for each dimension of BIM, we moved on to the most important phase of our study: the analysis of the data and the representation of these to help during the Early Design Stage as a Decision Support System (DSS).

As a first step, we used another *Grasshopper* plug-in: *Colibrì by CORE Studio|Thornton Tomasetti*[71]. Thanks to this plug-in we were able to choose the parameter we wanted to test and record the values of the others as they changed. The values of every single configuration are automatically exported to an external Excel file defined by us. In addition, it is possible to simultaneously save an image representing the specific configuration and/or the 3D model (a 3DObject).

Summarizing the parameters calculated in the previous chapters, the outputs we have obtained are the following:

- N°. different panels;
- N°. total panels;
- Thermal transmittance U [W/m^{2}K];
- H't;
- LCA (PE_{REN}/PE_{TOT});
- N°. total anchors;
- Installation time (gg);
- Total cost (€/m^2).

Having based our research on panelling the facade of the building, **the element that has been made to vary is that relating to the size of the panels**: all these above parameters have been influenced accordingly.

Design Explorer

The goal of our study has always been focused on interoperability and the ability to collect information in **open-source software.** To allow everyone to view the configurations obtained, it was decided to use the *Design Explorer* tool *by CORE Studio|Thornton Tomasetti*[95].

The results obtained with *Colibrì*, a tool developed by the same company of *Design Explorer*, are saved in a format ready to be imported on the latter. As has been said, however, *Design Explorer* is an open-source tool, so the results must be previously moved online: for this reason, the folder containing the data of the various configurations has been copied to our *Google Drive*[96]profile.

Once the results have been inserted in *Design Explorer*, a **link is provided which is the reference that allows anyone to access the platform**: this can be provided, for example, to the customer who wants to see the possible solutions.

The tool is very intuitive and allows you to:

- Highlight the only solutions that respect specific sub-ranges for each parameter defined by us.
- Reorder the solutions from the best-performing ones to the least performing ones (or vice versa) for each parameter.

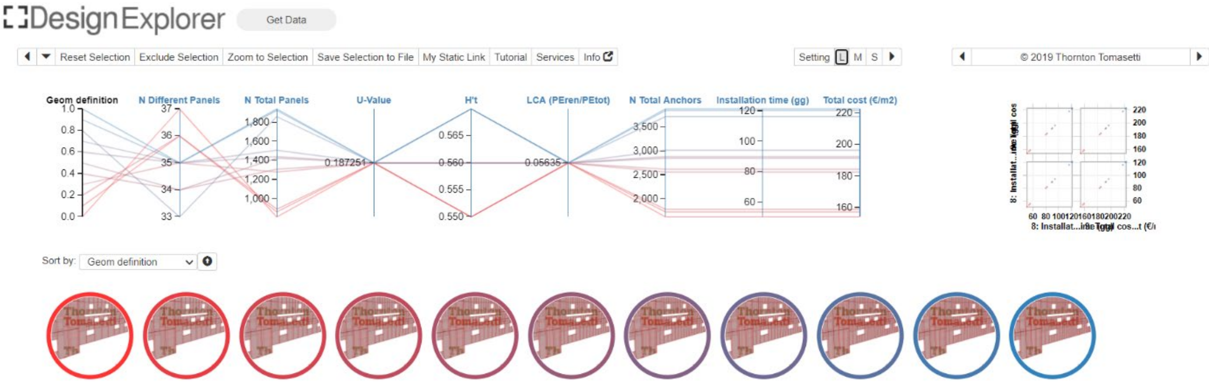


Figure 5.1_ Design Explorer home page - EASEE solutions

The usefulness of this tool lies in the fact that:

- **Anyone can view the results and interact with them**, analysing which solution may be the most suitable according to their needs (very often those of the client, architect, designer, cost manager… differ).
- Immediately have a **preview of the model** corresponding to each configuration, thus associating the aesthetic (no less important) with the statistical data.

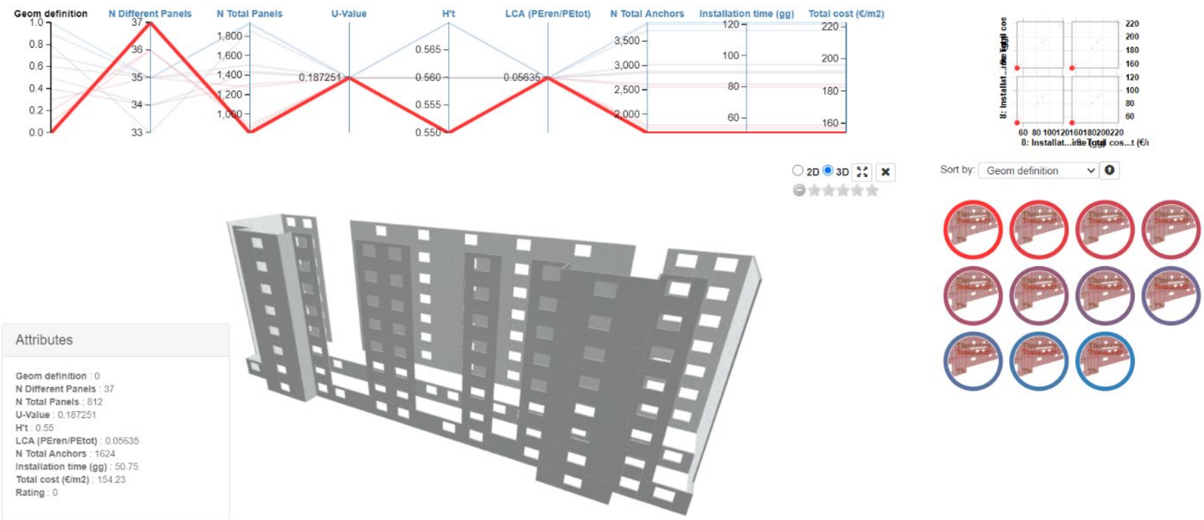


Figure 5.2_ Design Explorer - EASEE configuration_0

Design Explorer reference link for EASEE solution: *https://tt-acm.github.io/DesignExplorer/?ID=BL_2NXOEzJ*

Design Explorer reference link for TES solution: *https://tt-acm.github.io/DesignExplorer/?ID=BL_3rr1Hav*

Spider diagram

The results obtained are analysed more in-depth in Grasshopper. It was decided to show the values obtained in the spider diagram, a very useful and readable tool for understanding the results.

Now, the aim is to evaluate the different configurations as objectively as possible, showing the results according to normalized scores, therefore valid in each case study; in addition, for a quicker view, we have tried to group the parameters belonging to similar categories under a single parameter.

To do this, we have decided to represent the data in 3 different types of diagrams, to be able to appreciate the pros and cons of the different configurations clearly and thoroughly.

As a first step, we have defined the domains within which every single parameter analyzed must be to let the corresponding configuration be positively considered by us. The limits of these domains, as mentioned before, are universal, but eventually, they can be fully customizable to best respond to the needs of the customer and the other parts of the project. Thanks to the constraints, it was possible to make a first screening of the results: therefore, **all the configurations shown in the following graphs are plausible solutions (differently from Design Explorer)**.

The following domains were chosen:

- **N°. Total panels/Total Area [n.panels/m^2]**: **0 ≤ Acceptable ≤ 1**

To represent the values regarding the total number of panels, we have decided to convert the data to the square meter of surface. This allows us to create a domain that is valid for each case study, regardless of the different surfaces on which we are intervening.

The maximum limit of 1, indicates the worst configuration, which would have a large number of panels. This is an aspect that heavily influences other parameters, first of all, the total installation time of the panels.

The closer the values are to the lower limit of 0, the larger the panels used are and therefore allow the surface to be panelled more quickly.

- **N°. Different panels/N°. Total panels [-]**: **0 ≤ Acceptable ≤ 1**

To represent the values regarding the number of different panels needed, we decided to calculate the data as a percentage, dividing by the total number of panels. Also in this case, therefore, we have an output that allows us to compare the results of different case studies, objectively and not dependent on the surfaces considered.

If a configuration reaches the maximum limit of 1 (the worst), it would mean that each panel is unique (it has different dimensions from the others).

- **Thermal transmittance U [W/m^{2}K]**: **0.13 ≤ Acceptable ≤ 0.26**

To determine the lower limit of this domain, we thought about which thermal transmittance value could be considered optimal and at the same time realistic (achievable). We have decided to consider U_{min}=0.13 W/m^{2}K as the lower limit.

To determine the upper limit of this domain, we followed the maximum permissible value by law for opaque perimeter walls. Since our case study is located in climatic zone E, U_{max}=0.26 W/m^{2}K.

- **H’t [W/m²K]**: **0.30 ≤ Acceptable ≤ 0.75**

To determine the lower limit of this domain, we thought about which global mean coefficient of heat transfer could be considered optimal and at the same time realistic (achievable). We have decided to consider $H't_{min}$=0.30 W/m²K as the lower limit.

To determine the upper limit of this domain, we followed the maximum admissible value by law based on the reference climatic zone (E), the type of intervention we are going to carry out (important level I requalification) and the S/V ratio. Since our case study is located in climatic zone E and S/V < 0.4, $H't_{max}$=0.75 W/m²K.

- **LCA [PE_{REN}/PE_{TOT}]**: **0 ≤ Acceptable ≤ 1**

To determine the limits of this domain, we thought that the extreme values 0 and 1 are difficult to reach but not impossible. It is possible that some configurations are made of non-renewable materials that would bring this parameter closer and closer to the value 0. It is much more complicated to reach the upper limit equal to 1 which would mean having found a totally renewable configuration. However, for the purposes of the readability of the values of this parameter, we have considered it correct to choose these two limits.

- **N°. Anchors/Total Area [anchors/m²]**: **0 ≤ Acceptable ≤ 2**

To represent the values regarding the total number of anchors, we have decided to convert the data per square meter. The total number of anchors is then spread over the total square meters of the surface being panelled.

As an upper limit, it was decided to consider 2 anchors per square meter. We did a study to verify if this value was plausible: we selected the smallest panel we could have in the building (EASEE panel 1.84x0.41 m), with an area of 0.75 m², and we found that 2 shear anchors are required; this means that we need 2.6 anchors per square meter. Considering, however, that these are the smallest panels that we can have in the building and that therefore the anchors will be more scattered, we have reduced this value to 2 anchors per square meter.

- **Installation time [h/m²]**: **0.02 ≤ Acceptable ≤ 0.27**

For the installation time, defining absolute limits, valid for each case study, is not an easy job. This is because the timing of the prefabricated and traditional configurations was calculated differently: for the ETICS system, the total duration was calculated starting from the hours per square meter necessary for the operational team to complete the work; for the EASEE and TES systems, on the other hand, the total duration was calculated starting from the hours required to install a panel. This is because the panels are of different sizes and it is more accurate to estimate the time required for handling them with a mobile crane until the complete installation. In conclusion, it is difficult to find a normalized value that allows us to compare the 3 configurations in an absolute way. At this point, we decided to impose limits that are plausible for the renovation of a medium-large building (like our case study) and divide these by the total area of intervention. In this way, we have been able to obtain a range per square meter that allows us to absolutely compare case studies of similar dimensions. If, however, a much larger building was studied, obviously, the times would increase and therefore it would be necessary to change this range. As a minimum, we chose 7 working days, which divided by the square meters of the facade and transformed into hours, resulted in 0.02 h/m².

As a maximum limit, we assumed that the client expressed the need to complete the work in a maximum of 3 months of work. For this reason, we have chosen 90 days as the upper limit, which converted into hours per square meter equals 0.27 h/m^2.

- **Total cost [€/m^2]: 80 ≤ Acceptable ≤ 250**

To determine the lower limit of this domain, we have selected the average price of the solution that theoretically should be the cheapest on the market, i.e., the ETICS system. Considering that the price can generally be around 50/100 euros, we have decided to select 80 euros as the lower limit.

To determine the upper limit of this domain, we know that the EASEE solution has a price of around 150 euros per square meter, while we do not know for sure the cost of the TES solution. From research carried out, we have found that the price of a solution approximately comparable to the TES one, is around 200/300 euros per square meter (solution with new wood infill, complete with internal counter-wall and coat+external finish). As the TES solution is therefore the most expensive, we have decided to select 250 euros per square meter as the upper limit.

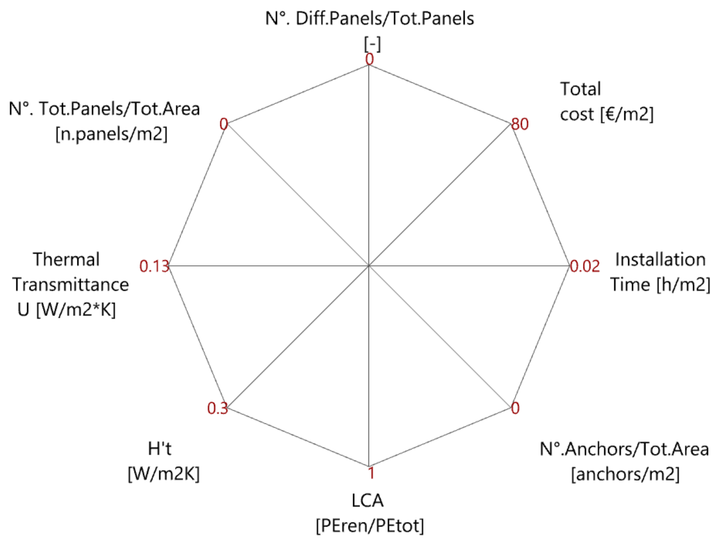
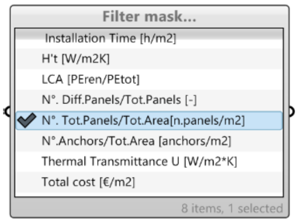


Figure 5.3_ Spidergram with the selected parameters.

Diagram 1 – Value-based



The first type of diagram we have developed represents each solution that respects the domains previously defined, based purely on their analytic values.

It is possible to select the best solution for each specific parameter, thanks to a "Value Set Picker".

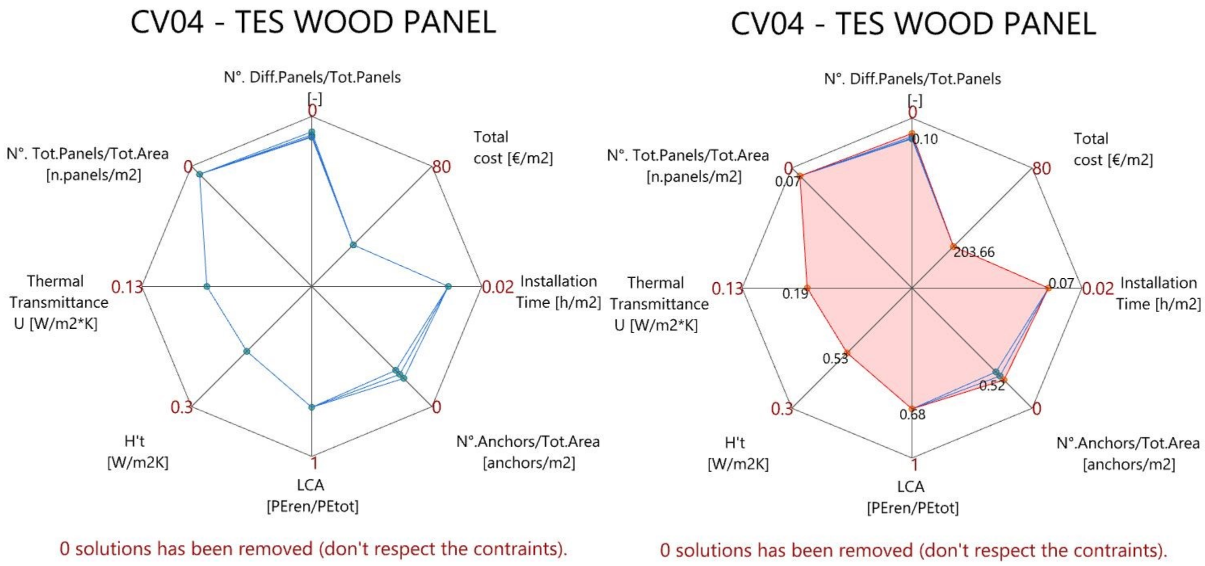


Figure 5.4_ TES diagram 1 - all acceptable solutions (left), selection of best solution for "N°.Tot. panels/Tot. Area" (right).

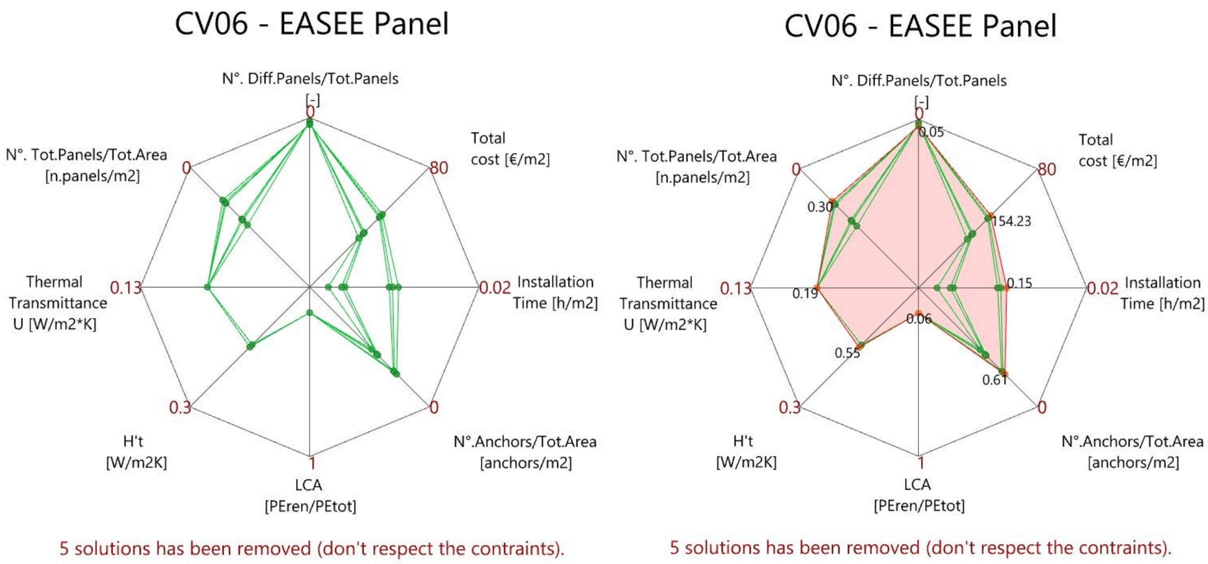


Figure 5.5_ EASEE diagram 1 - all acceptable solutions (left), selection of best solution for "N°.Tot. panels/Tot. Area" (right).

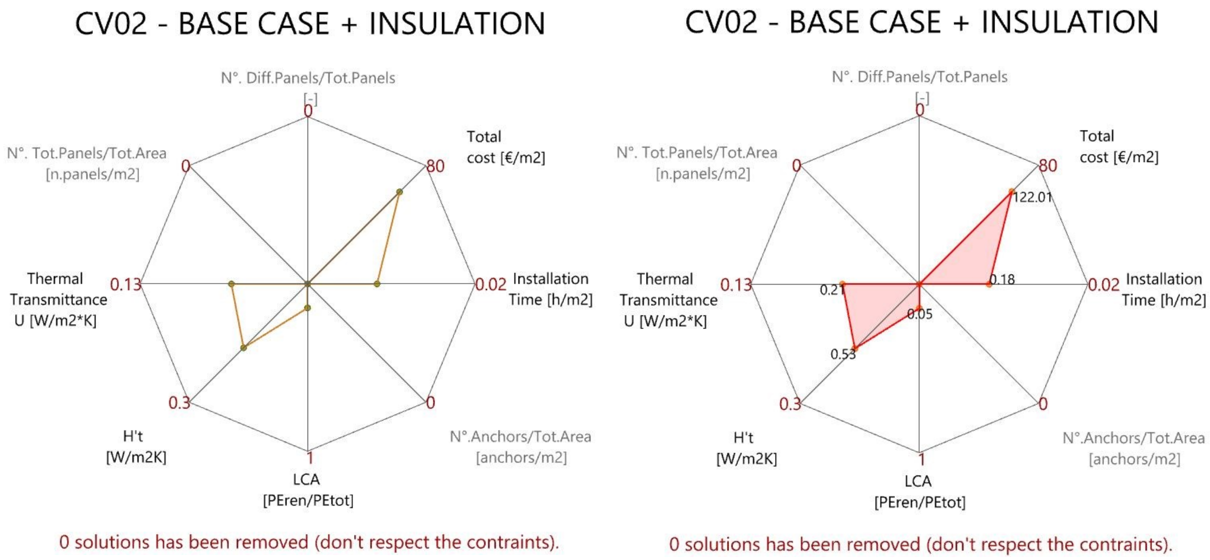


Figure 5.6_ ETICS diagram 1 - the only solution analyzed respects the constraints (n°. 2 work teams).

The ETICS configuration, since it is a traditional technology, has no prefabricated panel and for this reason, its parameters are evaluated as null: “N°. different panels”, “N°. total panels” and “N°. total anchors". **Having decided in our analysis to vary the dimensional parameter of the panels, the ETICS system (lacking this parameter) has only one possible solution**.

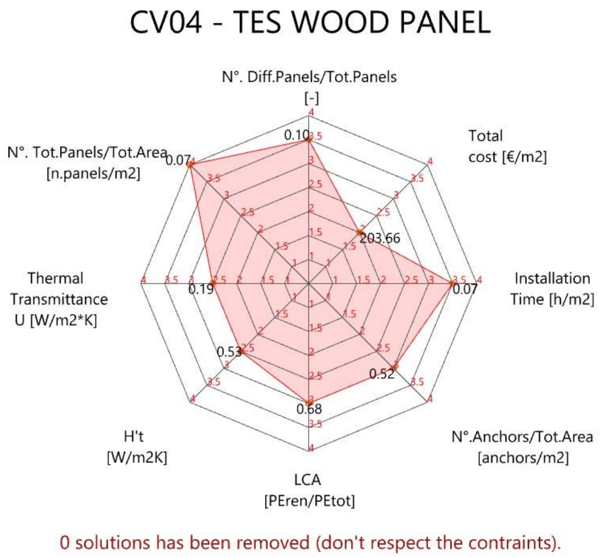
Furthermore, as expected, the ETICS solution presents greater labour on-site and the installation times of the system can be much higher than the EASEE and TES configurations.

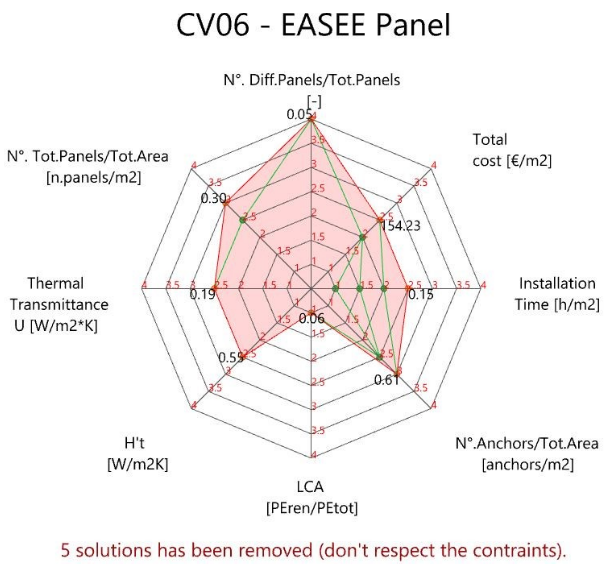
We obtained the results for each configuration **considering a single work team**, but we noticed that the **installation times** of the ETICS system in this way become really long (**265.5 days = 0.79 h/m^2**), beyond the domain we defined for the item “Installation time (h/m^2)” (max. limit = 0.27 h/m^2).

In order to be able to compare an **ETICS configuration** with the other two types, we have decided to **increase its number of work teams to two**. This made it possible to reduce the **installation time** to **61.18 days = 0.18 h/m^2**.

Diagram 2 – Grade based

The second type of diagram has the same configurations as before, **evaluating the values on a scale from 1 to 4 (1 is the worst, 4 is the best)**.





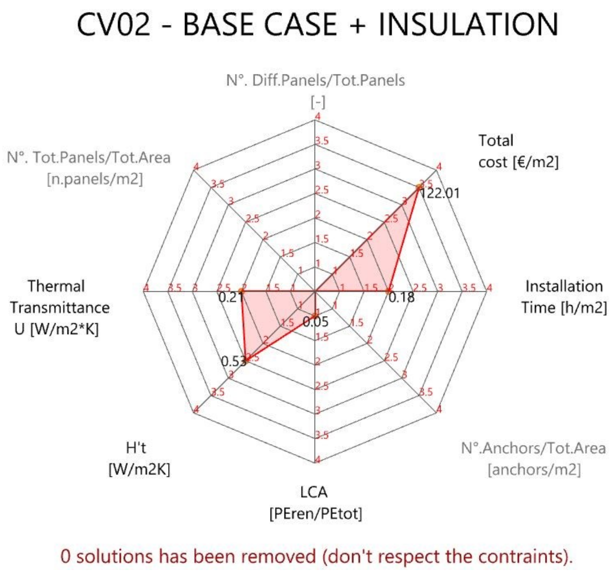


Figure 5.7_ Configurations diagram 2 - Selection of best solution for "N°.Tot. panels/Tot. Area" (red).

Thanks to this type of diagram, it is much more immediate and easier to evaluate the results obtained.

Diagram 3 – Average Sum Grade based

The third type of diagram allows us to have a quick evaluation of the configurations, without having to view each parameter analysed, individually. To do this, we have grouped the previous grades (from 1 to 4) **according to the different dimensions of the BIM**. For the **parameters classified under the same category**, an average of the respective marks was made.

The parameters were divided into the following disciplines:

- **Structural Design (2D):** -N°. Anchors/Total Area [anchors/m^2].
- **Geometry Definition (3D):** -N°. Different panels/Total panels [-];

  -N°. Total panels/Total Area [n.panels/m^2].
- **Time (4D):** -Installation time [h/m^2].
- **Cost (5D):** -Total cost [€/m^2].
- **Environmental Design (6D):** -Thermal transmittance U [W/m^2*K];

  -H't [W/m^2*K].
- **Management (7D):** -LCA [PE_{REN}/PE_{TOT}].

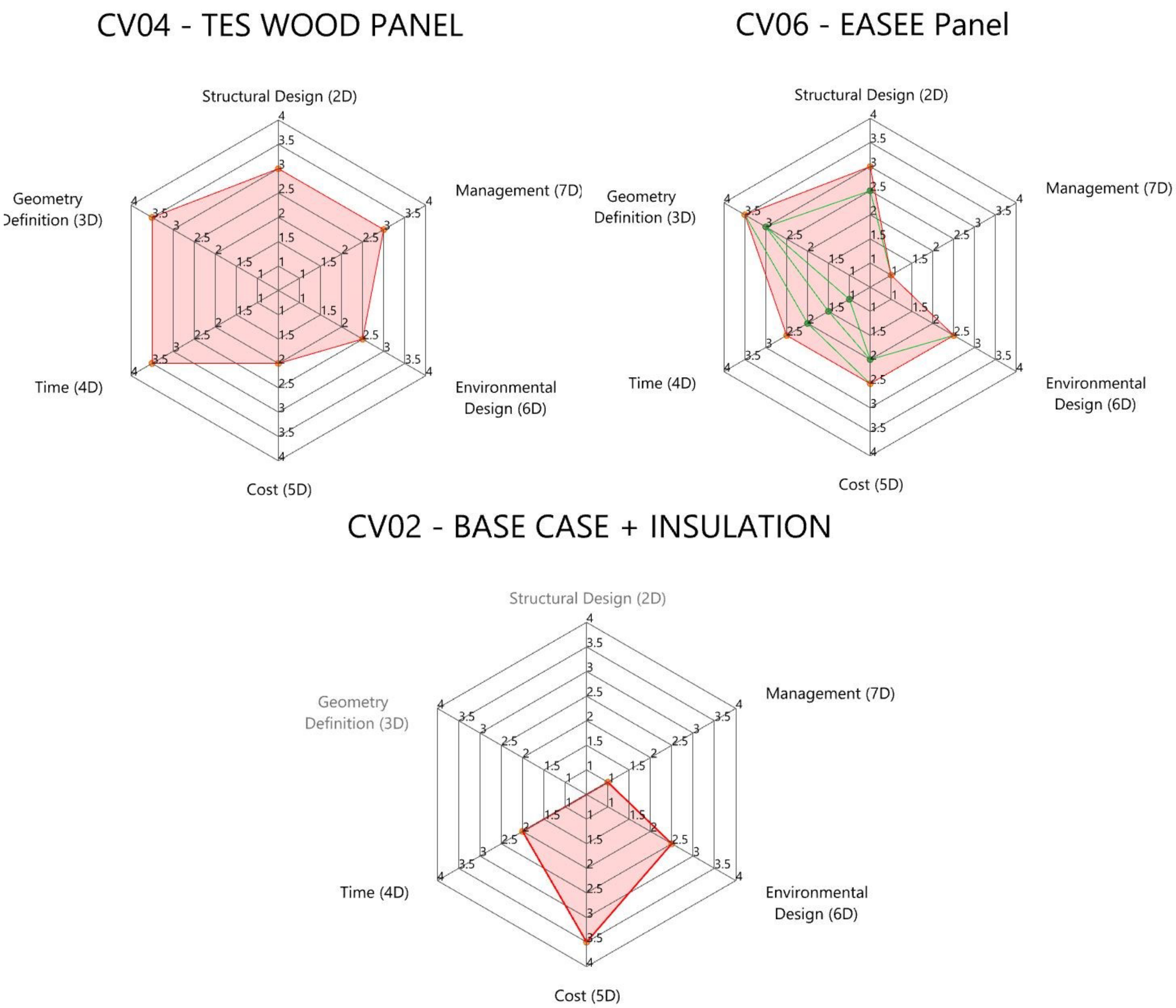


Figure 5.8_ Configurations diagram 3 - Selection of best solution for "N°.Tot. panels/Tot. Area" (red).

Final comparison

As the last graph, it is possible to obtain the **results of the 3 configurations ETICS, EASEE and TES, according to diagram type 3, all together**: this allows us to compare and evaluate in a simple and intuitive way the pros and cons of the different configurations.

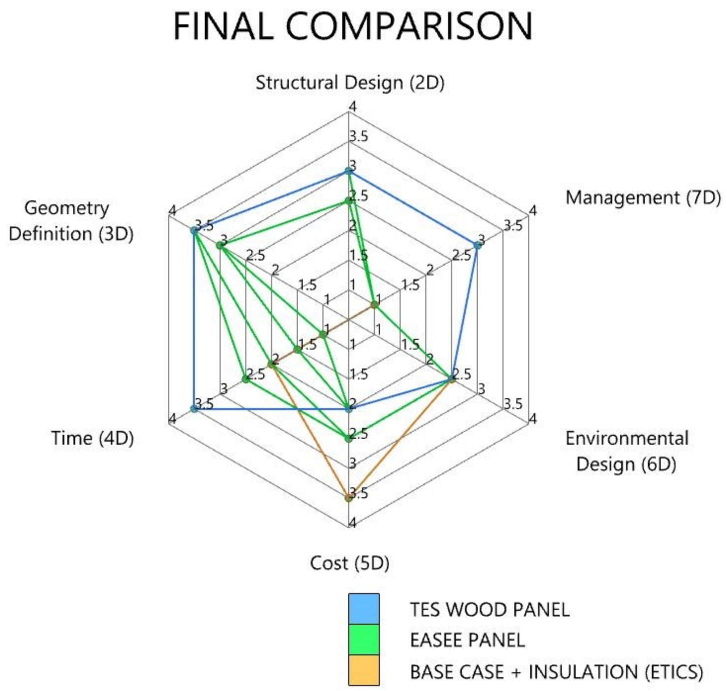


Figure 5.9_ Final comparison - All the possible solutions that respect the constraints.

Also in this final case, if necessary, we can compare solutions of particular interest:

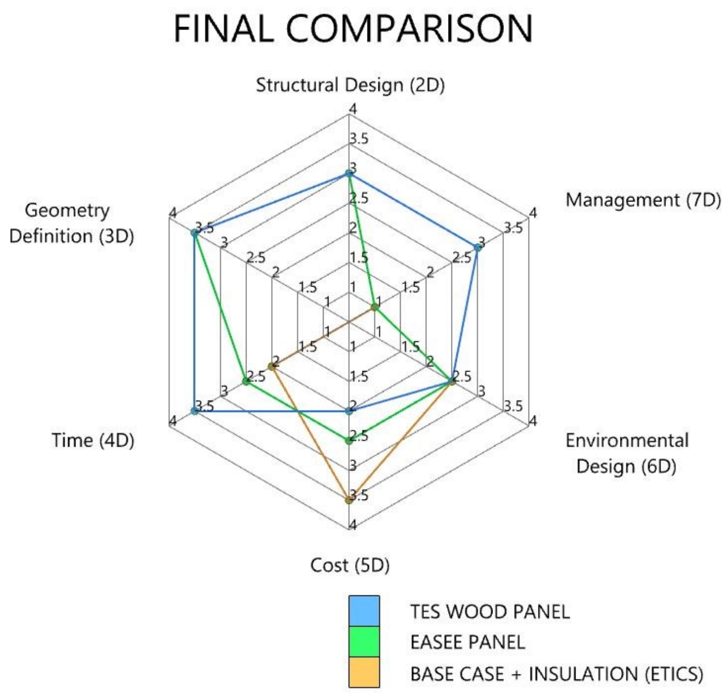


Figure 5.10_ Final comparison - Comparison of best solution for "N°.Tot. panels/Tot. Area" (inside "Geometry Definition 3D").

What we can deduce from the results shown, is that the **TES solution is the most performing**.

If we **compare only the TES and EASEE** solutions in *figure 5.10*, we can see that:

- In "Structural Design (2D)", the two solutions have a rating equal to 3. This is because the TES need more anchors but for a smaller number of panels than the EASEE solution, so the final score is equal.
- In "Geometry Definition (3D)", the two solutions have an evaluation equal to 3.5. This is because the TES have a better evaluation in terms of "N°.Total Panels/Total Area", while the EASEE in terms of "N°.Different Panels/N°.Total Panels", the final average places both solutions on the same score.
- The "Time (4D)" item stands out for being one of the parameters in which there is the greatest difference in votes between the configurations. The TES solution has a rating of 3.5, while the EASEE of 2.5. This is because the high number of EASEE panels compared to TES ones (at best, the total number of EASEE panels is 4 times that of TES), takes much longer to complete the installation as the crane has to do a lot more handling.
- Under the item "Cost (5D)", the TES solution has an evaluation equal to 2, the EASEE equal to 2.5. This is the only parameter in which the TES solution has a lower score than the EASEE one. This is because high-performance products always cost more than lower-performance ones. The production of a much more complex panel than the EASEE one (which is instead a simple sandwich panel), the shorter installation time, and the best environmental and management properties (see the next two items in the list), mean that the price is higher than that of the other solutions.
- In "Environmental Design (6D)", the two solutions have the same score. This is because, as we could see from the H't analysis, the overall building losses with TES panels are not significantly lower than those with EASEE panels.
- The parameter "Management (7D)" highlights the biggest difference between these two solutions. The TES solution is largely made up of wooden material and therefore renewable, while the EASEE solution, made up in part of cementitious material, has a much higher environmental impact.

If **we compare the ETICS system with the two prefabricated solutions**, we can see that:

- In "Time (4D)", the ETICS system has the lowest rating even though we have considered two work teams. This is because the time considered is that on-site and the ETICS system does not have the advantage of prefabricated solutions of arriving at the site already with the panel ready to be installed.
- In "Cost (5D)", the ETICS system has the best rating, therefore it is the cheapest solution. This is because it is the solution that can be subject to more inconveniences and delays. For example, it is not impossible to find low energy performance of the building even after the redevelopment; this is because it depends on how the layers are installed on-site by the work team. Therefore, certainly, the competence of the work team is of great importance (not surprisingly, in the ETICS system, labour is the most expensive item compared to the cost of materials and rentals). However, we must be careful as installation times have a big impact on the rental of machinery (first, the scaffolding), and if these last too long, we could even arrive at a case where the ETICS system costs more than prefabricated solutions.

- In the items “Environmental Design (6D)” and “Management (7D)”, the ETICS solution has a final evaluation equal to that of the EASEE system. Although the ETICS system offers greater continuity of the insulation along the facade of the building, the EASEE solution analysed has thicker insulation that allows it to counterbalance the losses due to linear thermal bridges.

Although we have defined the TES solution as the best performing, we do not want to define this as the solution that the hypothetical client should choose. This is because, as already said several times, the purpose of our study is to create a tool for the *DSS*, so we have tried to show the results obtained as clearly as possible to help those in charge, in making the right decision. In a project, there can be many variables that can lead the client to lean more towards one solution rather than another. We limit ourselves to showing what has been obtained and giving an objective evaluation of the results.

Revit export

CHAPTER'S SUMMARY:

As a *first design step* we took care of the **import** of the 3D geometries modeled on Revit into Rhinoceros and now, as last step we take care of the inverse process, that is to bring the systems analyzed by Rhinoceros into Revit (**export**). **All the analyzes** have been carried out and described, now the design choice with which to proceed can be any of them. Because the choice can fall on any of the three solutions, the export of each of them has been managed separately.

From what we have done in the previous chapter, we have gathered all the data necessary to support our design choice and, since the tool we are describing aims to export what has been analyzed in the BIM environment, we have tried to give an answer to this topic too.

The plugin we have chosen for the export is **Rhino.Inside.Revit**, which we have already described in terms of pros and cons in Chapter *4.2 "Export from Revit"* and therefore here we will focus on all the new information that are not repetitions of what has already been saying. The plug-in allows you to **create elements in Revit through Grasshopper components as if they were native to the software** itself. For this reason, all the logic for creating walls, floors, etc. must respect the logic of Revit and this is important to underline because it guides all the export logic.

Since the three types of walls are new constructions, if we had to carry out the operation of drawing a wall on Revit, we would have had to select an existing Type and draw the line along which this wall develops. In the same way, if we wanted to repeat this operation from Grasshopper, **the inputs required** by the component are:

- Base **curve**;
- **Type** belonging to the Wall Category;
- Reference level (optional);
- Wall **height** (optional);
- Position of the Wall with respect to the line just drawn (optional);
- Flip of the wall with respect to its vertical mean plane (optional);
- Allow joins (optional);
- StructuralUsage (optional).

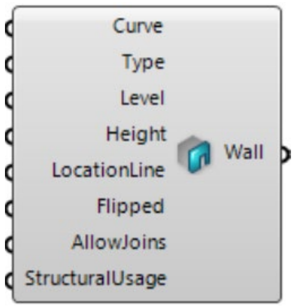


Figure 5.11_ "Add Wall" component

Nothing more than we would normally do in Revit, in short.

Before proceeding with an explanation of the individual cases, we anticipate that **the plug-in is still in Work in Progress** and that therefore some limits have been found in the modelling. An example above all concerns the case of TES geometries, which is similar to Curtain Wall walls are slightly more complex than the ETICS and EASEE cases where the walls are designed as simple layers put together. Apart from the modelling of the panel itself, a big problem we encountered was that of the presence of openings and although we have tried to solve the problem through automated procedures (without single manual operations of walls cutting) we have not succeeded also since this and other operations will be implemented in the coming months.

We would therefore like to say that in the short future, **certain steps should be able to be completed more quickly and automatically through an appropriate script**.

In order to have even more autonomy in the management of the chosen technologies, thanks to another component present in the Grasshopper script, **we are able to modify the thicknesses of the layers of the Family_Types**. In Revit, a duplicate of the *Family_Type* we are editing is automatically created, having the same properties as the original but a new name and the thickness of the layers we have defined.

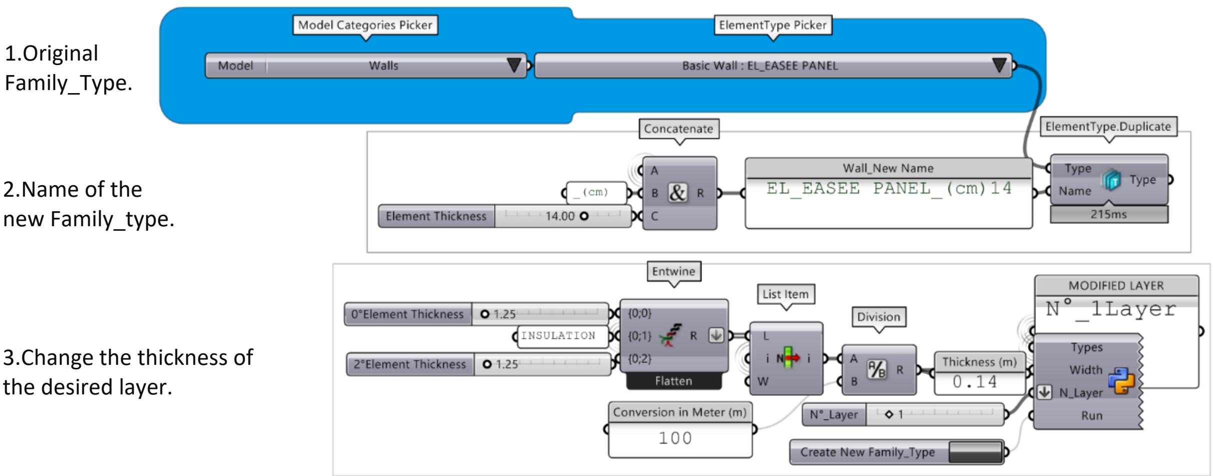


Figure 5.12_ Script section for modify layers thickness – EASEE solution.

PANELS

ETICS

The thermal insulation panels were modelled starting from the basic curves of the 3D solids obtained from Rhino/Grasshopper and then exported according to the EL_ETICS Type, consisting of:

- Lightweight Mortar, thickness 15 mm
- Insulation Frontrock Max E, thickness 120 mm
- External finishing, thickness 6.5 mm

EASEE

Even prefabricated EASEE panels have been modelled starting from the base curve of the 3D solids modelled in the Rhino/Grasshopper environment; have been exported using the EL_EASEE Wall Type composed of the following layers:

- TRC-Textile Reinforced Concrete, thickness 12.5 mm
- Insulation EPS, thickness 140 mm
- TRC-Textile Reinforced Concrete, thickness 12.5 mm

Figure 5.13_ SOUTH - Final case study model with EASEE panels.

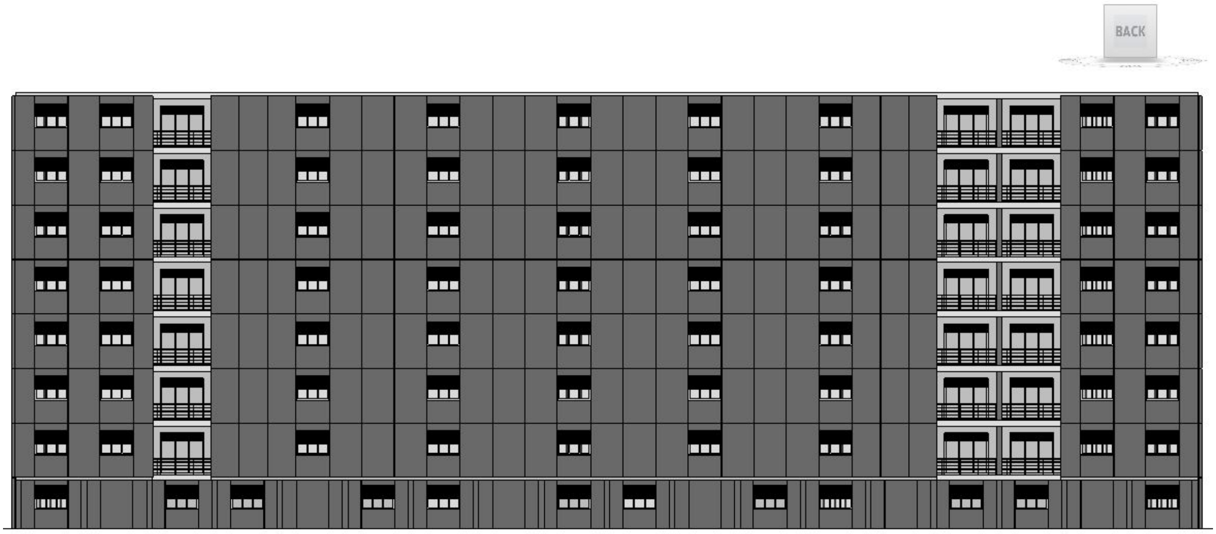


Figure 5.14_ NORTH - Final case study model with EASEE panels.

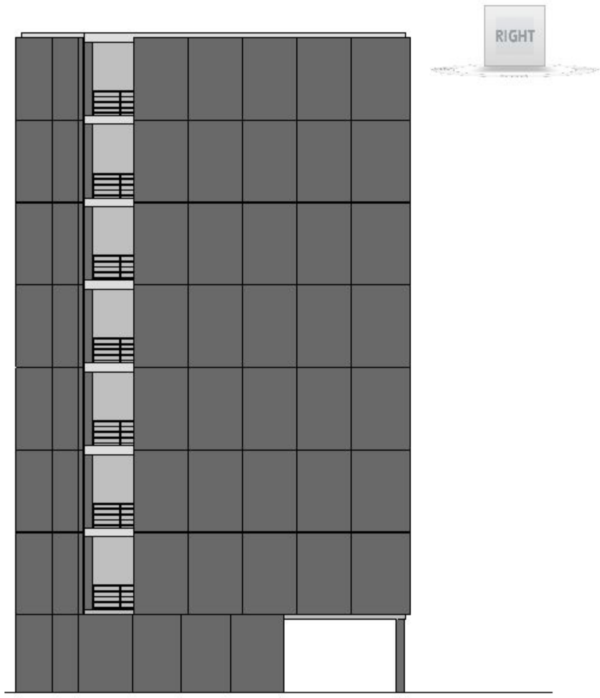


Figure 5.15_ EAST - Final case study model with EASEE panels.

Figure 5.16_ SOUTH PERSPECTIVE VIEW - Final case study model with EASEE panels.

TES

Regarding the type of TES panels, the modelling was done in a slightly different way. It is not enough to model the layers because **the system is comparable to a Curtain Wall** with wooden mullions and transoms with intermediate insulation panels + OSB finishing plates; a ventilated facade system is then externally applied, with load-bearing elements in wood and finishing in wooden boards. The steps are therefore different from what we have seen for the other solutions and required a greater design effort, especially when we faced the need to **create holes for the windows** located behind the existing wall. What we were looking for, was an automatic procedure - just like all the other steps that lead to the definition of the retrofit panels - without the need to manually drill multiple walls in Revit. Unfortunately, this **has not been achieved, also due to the Work in Progress of the software itself. Without forgetting the need to indicate these openings**, **we** have limited ourselves to **highlighting the portions of the façade that would be subject to a cutting action, hoping that it will be possible to implement the thing as soon as possible.**

Below is the composition of the two Curtain Walls. The first consists of:

- OSB wood panel, thickness 22 mm
- Stone wool Insulation panel (Fixrock 35 F) + wooden mullions, thickness 120 mm
- OSB wood panel, thickness 22 mm

while the ventilated facade is composed by:

- Air cavity + counter battens (ventilated facade substructure 48x36 mm), total thickness 72 mm
- Rockpanel wood cladding, thickness 8 mm

Figure 5.17_ SOUTH - Final case study model with TES panels.

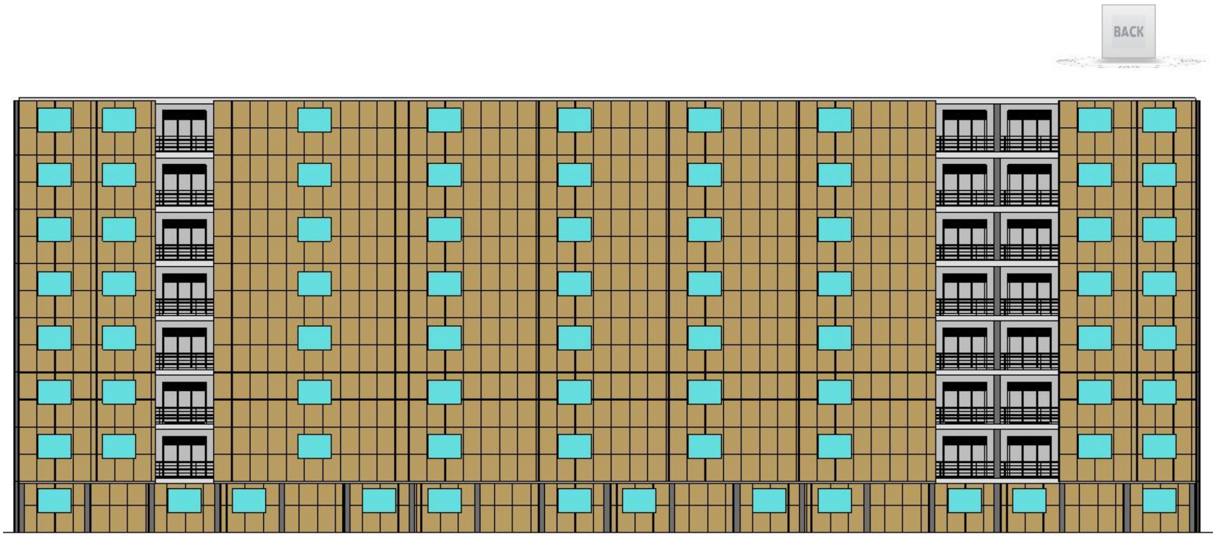


Figure 5.19_ NORTH - Final case study model with TES panels.

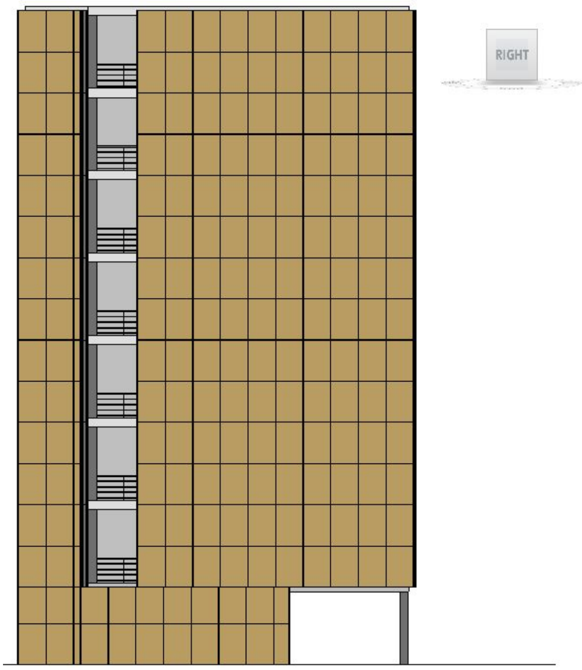


Figure 5.20_ EAST - Final case study model with TES panels.

Figure 5.18_ SOUTH PERSPECTIVE VIEW - Final case study model with TES panels.

CATALOGUE

The goal from the beginning was to be able to create a continuous workflow that would act as a reference for BIM modelling and therefore, as we have said several times, ***in addition to the geometries it is necessary to include all the information that accompanies the classic three-dimensional modelling***.

For this reason, it is not enough to think of being able to have a catalogue of the panels only in textual format (which happens in both the Grasshopper and Excel environments), but it is mandatory to be able to associate this information with the geometry to which it is linked. This concept is the very essence of ***BIM modelling*** and therefore could not be overlooked.

How to do this, however, has been the subject of a little discussion. Each ***parameter*** is intrinsically representative of an aspect of the element that we are analyzing and therefore serves to describe and detail the various aspects of the design. For the purposes of our analysis, however, what we were interested in doing was to establish, parallel to the flow of geometries, a flow of information. For this reason, we have limited ourselves to associating the tags relating to the catalogue - created on Grasshopper and defined as per Chapter *4.5 "Analysis_Geometry Definition_Panel catalogue"* - of the panel to the ***Revit "Comment" parameter***. A more correct alternative could have been to create a strictly related parameter and assign the value of each element to this key. However, although the procedure would have been more precise, it would have involved understanding how to automate this for each element and therefore in terms of effort/benefits, it was not an advantageous approach.

The information is still transferred correctly, and we leave these suggestions and ideas for possible alternative approaches to any future implementations.

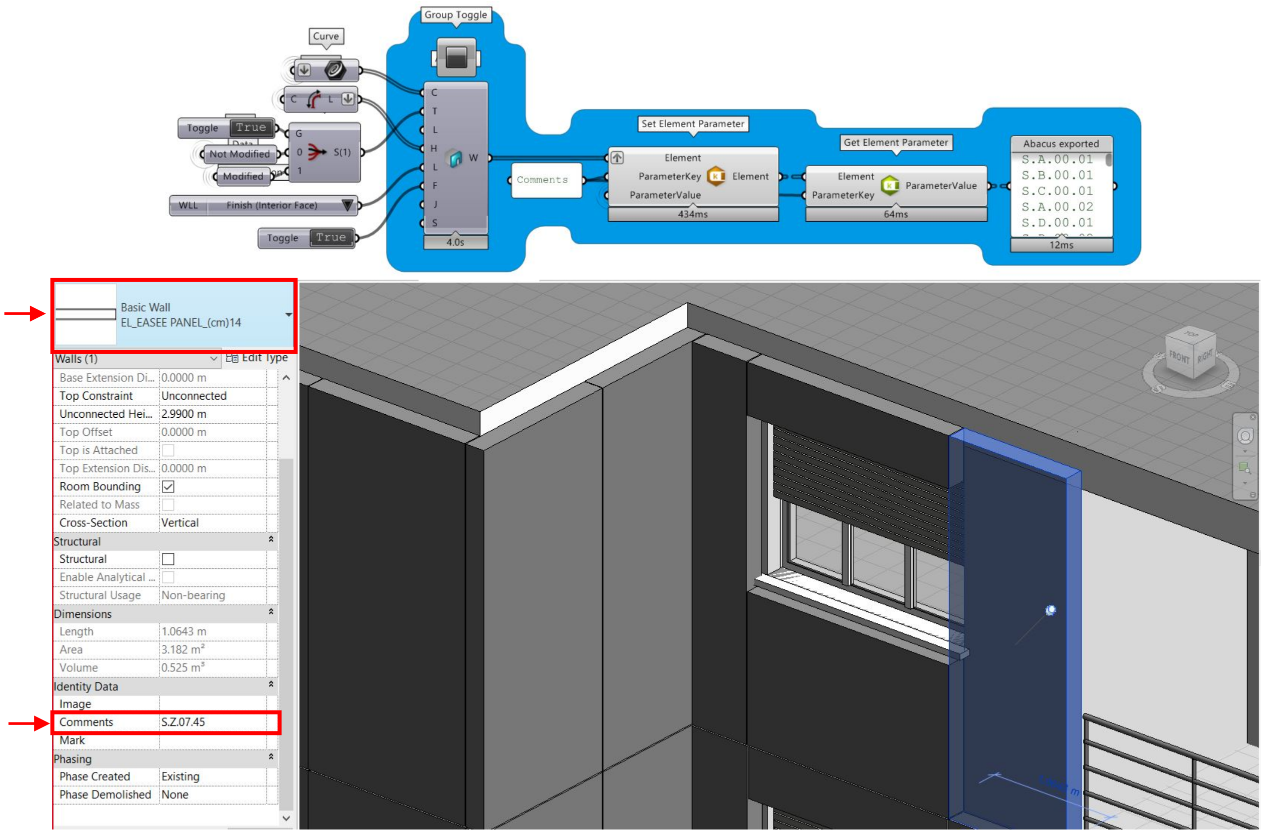
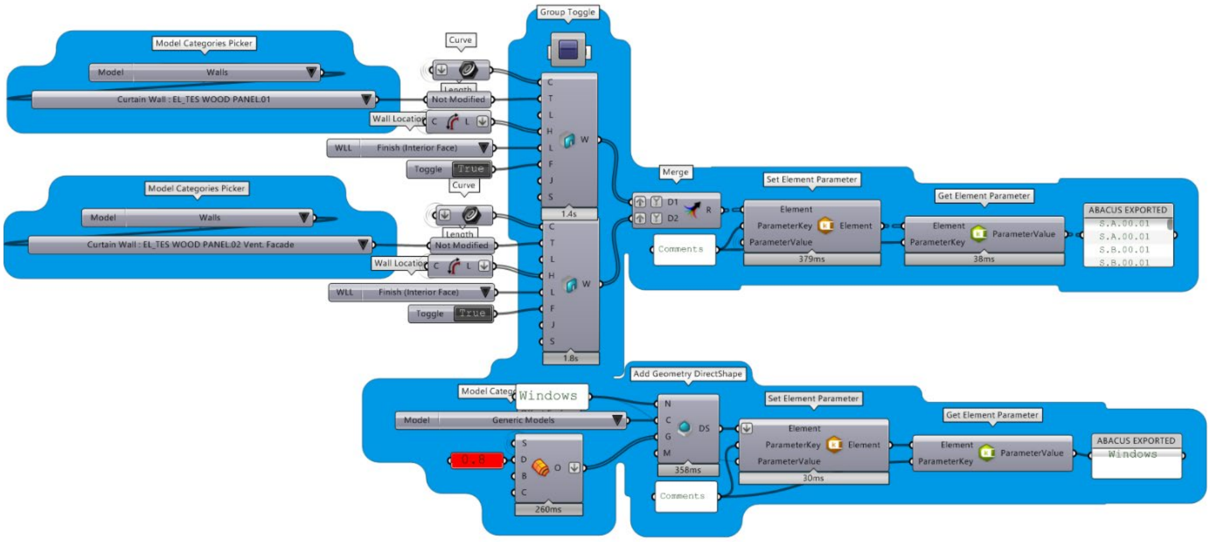


Figure 5.21_ Panel geometry exported with the catalogue information – EASEE solution.



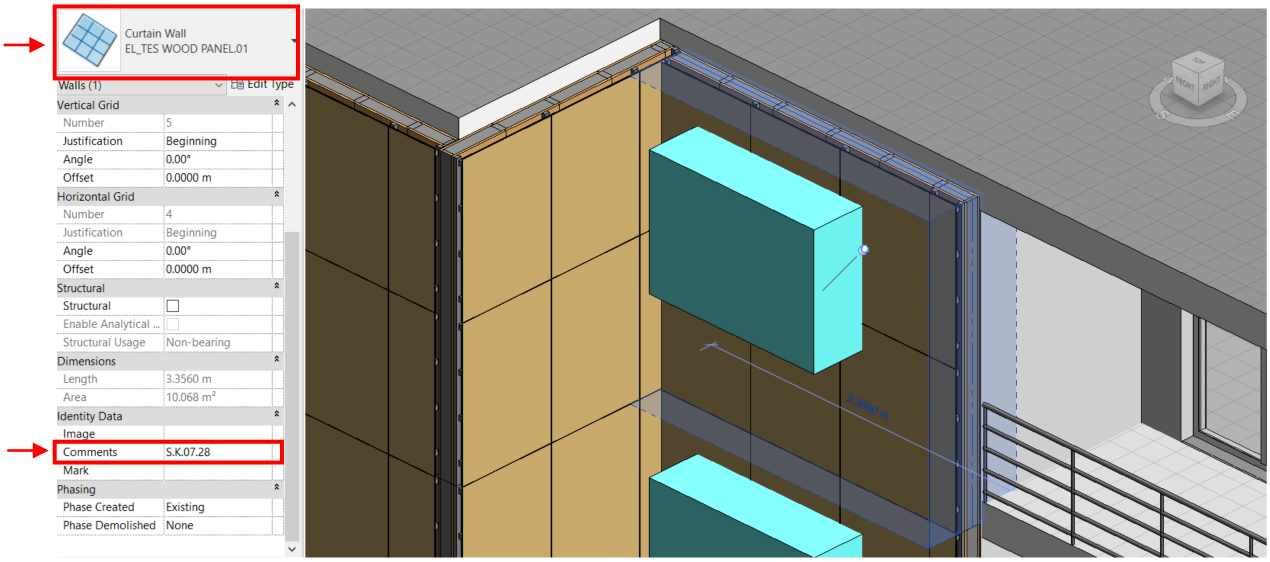


Figure 5.22_ Panel geometry exported with the catalogue information – TES solution.

Discussion

Today there are **many digital and information tools** for modelling energy redevelopment interventions of existing building panels [97] [98] [64]. Even if the common direction is that of Building Information Modeling (BIM) [99] [9] [100] [101], the fragmentation of the different fields of analysis, as well as that of the different project steps, slows down this transition process.

The reasons for these **problems** are different, but one of them is certainly the division between company-owned software - and therefore specific to certain products and types of applications - and research-related software. This concept can be generalized by highlighting how a common gap of this type of software are the limitations due to the low level of automation and, consequently, process optimization.

Specifically, the solutions related to the study of prefabricated panels have a great **need for interaction between the different disciplines**, much more than those made on site. These fields of investigation can be among the most disparate but are commonly associated with dimensions beyond the third: *Scheduling* (4D), *Estimating* (5D), *Sustainability* (6D), *Facility Management* (7D).

The presence of so **many variables**, combined with the need to carry out *numerous process iterations* to obtain an *optimal solution*, therefore represents perhaps the real obstacle in the development of this type of design. It is for this reason that new toolkits and opensource platforms have been developed which aim to have a **holistic approach** to the entire refurbishment intervention and which, also through evaluation processes, *reduce* the number of iterations necessary for operational decisions.

It is in this framework that the use of **parametric modelling software** (Dynamo, Grasshopper) is introduced, in addition to those of *geometric and information data management* (**BIM**). The advantages of this type of approach compared to common static software lie in the possibility of developing *iterations* of the design process and of having *rapidly output* through the definition of constraints and variables.

Through the use of these tools and moved by the concepts of building renovation and process innovation, we arrived at the definition of a **theoretical framework for the application of prefabricated technologies**. To do this it was therefore decided to investigate different options and in the end, we came to a focus on systems in a prefabricated sandwich-concrete-based panel and a prefabricated panel in Timber Frame; the comparison was made with a traditional ETICS (External Thermal Insulation Composite System) system to understand the strengths and weaknesses of each solution.

The **evaluation** of each solution analysed is carried out on the basis of the **scores achieved** by each, then grouped in an **easy-to-read graph** that can help all those involved in the remaking process in the **early-stage decision-making phases**. The choice is thus made based on a direct **comparison** at several levels and simultaneously on the basis of the indicated parameters.

In fact, we can consider the *first level of comparison* between the different macro-categories, thus identifying common behaviours among all the subsets (the sustainability of a wooden panel will generally be greater than that of a concrete panel, etc.), while we can identify the *second level of comparison* within the same redevelopment macro-type, or between the different configurations dictated by the various dimensional possibilities of panelization upstream of the analysis process (increasing the size of the panels will reduce the number of them for the same intervention surface, etc.).

From a critical point of view, this approach has a certain number of **weaknesses** too.

The first concerns the dependency of the script on the **Excel spreadsheet**. It allows us to insert inputs into the parametric software without the user having real visual programming skills while having clear the parameters and concepts behind them. This thing expands dramatically the audience of designers who can interface with the tool, extending its use to as many subjects as possible. This should not be underestimated, especially if we aim to create a holistic project methodology that involves as many aspects as possible. At the same time, however, the thing turns out to be highly limited due to the fact that the inputs in grasshopper are read indicating exactly the row and column number in which to read the value. It is therefore evident that even here we must know exactly what and where to get the references for the Grasshopper script. Any changes or implementations must be carefully managed and tested.

The other weakness - and *perhaps the most important* - is the ability to **manage the base model in Revit**. Although the plugin used constitutes in fact a new *and almost revolutionary* approach to the interoperability that it offers between the Rhinoceros and Revit software, it is not legitimate to think that this is able to optimally manage any type of three-dimensional model. As anticipated in Chapter *4.2 Revit file*, the export within the parametric design environment (Grasshopper in this case) takes place according to very specific rules.

First of all, the *flatness of the surfaces* must be respected as much as possible. At the moment it is not possible to manage a fragmented facade on several levels, but we are nevertheless confident that by continuing to implement the script we will be able to expand the range of possible solutions. The reason for this statement lies in the evolution process of the software itself, which started from analyzing a "simple" 2D surface up to the current 3D model. For this reason, we are counting heavily on possible future implementation.

Secondly, the *Type of Category* we are going to export must be known, whether they are walls or floors; this is essential to tell the software which BIM element to select (Filter) and then be converted into three-dimensional geometry in Rhinoceros. It comes by itself to think that without this data it is not possible to have a meaningful import and therefore the whole process stops if there are errors in this phase.

Finally, it is necessary to evaluate the process of selecting (or even creating) the *surfaces on which to operate*. Following the export process, the obtained geometries are not always ready to be fed to the panelling script; the reasons can be the most disparate but the most important are certainly the way in which Revit manages the priorities among the elements. However, it will be sufficient to create a different reconstruction process that takes this into account to be able to re-attach to the panelling part of the script. So the case-by-case problem is still manageable, with a relatively modest effort required.

3D Model Changes

The **script development process**, seemed to us to be such that it could stop at this point, leaving future implementations to future works. However, even if the tool has not been tested on other buildings than the one described here, some **modifications** have been made to the **Revit model** to verify that the process still remains valid and that further developments are possible - and desirable.

In particular, with reference to the Revit model under study, it was decided to remove a **stairwell**, a row of **balconies** and some **windows from the South facade**, **while the North facade** was lightened only in terms of **the number of windows**. This choice is motivated by the decision to operate at multiple levels of impact and above all on the elements that mainly characterize - in terms of shape and number - the BIM model. The absence of a stairwell leads to a profound modification in the script as it interrupts the continuity of the facade and therefore it is necessary to verify that the thing works in its presence/absence. A similar argument can also be made for the balconies, which appear to be façade interruptions but in the opposite direction. For windows, on the other hand, their importance is linked to the fact that they dictate the panelling geometries, both for EASEE and for TES: if in the first case their position distinguishes the portions of the surface included from the one above/below two consecutive openings, while in the TES the panelling script takes a point that lies in the space enclosed between two windows and therefore where two adjacent panels touch each other.

The **expected result** is that everything continues to work according to the same logic seen previously, providing new analysis outputs that we have collected and analyzed. Indeed, the test gives excellent ***results,*** and this justifies the desire to test the tool on other buildings in the near future.

What we have just described can be seen in the following images.

Figure 5.23_ SOUTH - EASEE panelization on the initial case study (above) VS the new model (bottom)

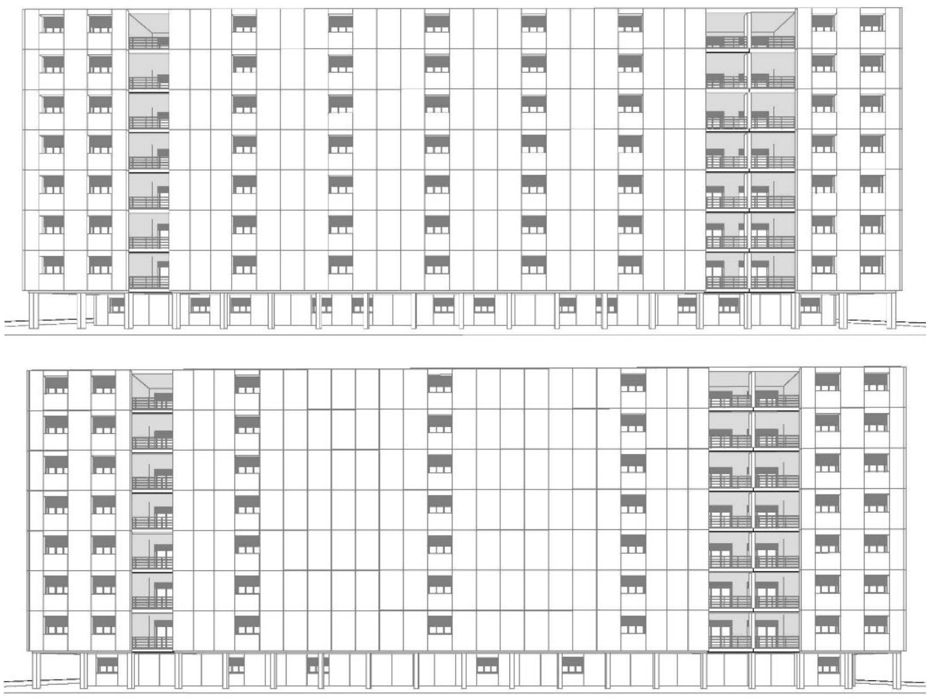


Figure 5.24_ NORTH - EASEE panelization on the initial case study (above) VS the new model (bottom)

We report only a comparative analysis between the results of the previous model (our main case study) and this one just studied, with EASEE panelling. Thanks to the developed spider-gram, we are able to test the results of the solutions even though the buildings have a different intervention surface.

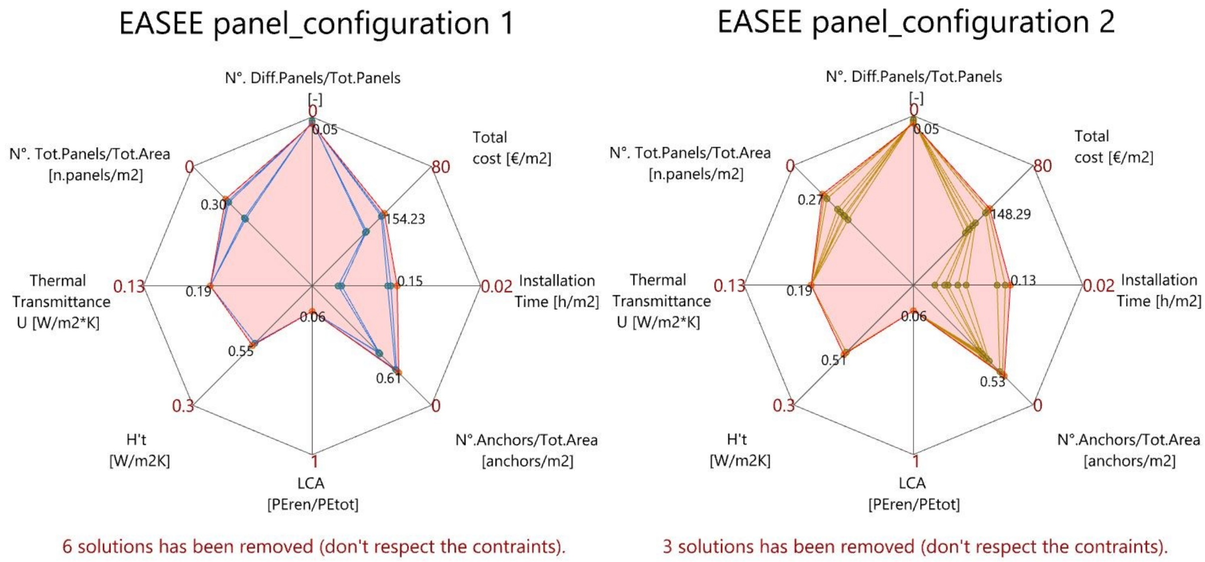
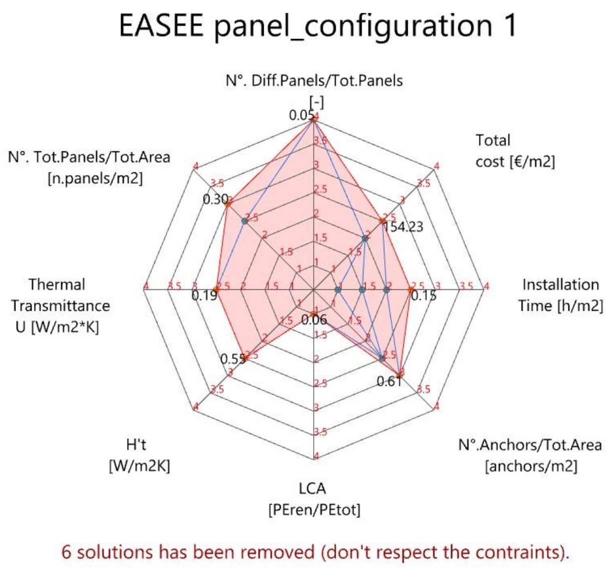


Figure 5.25_ EASEE diagram 1 - in red the best solution for "N°.Tot. panels/Tot. Area" for initial case study (left) VS for the new model (right).



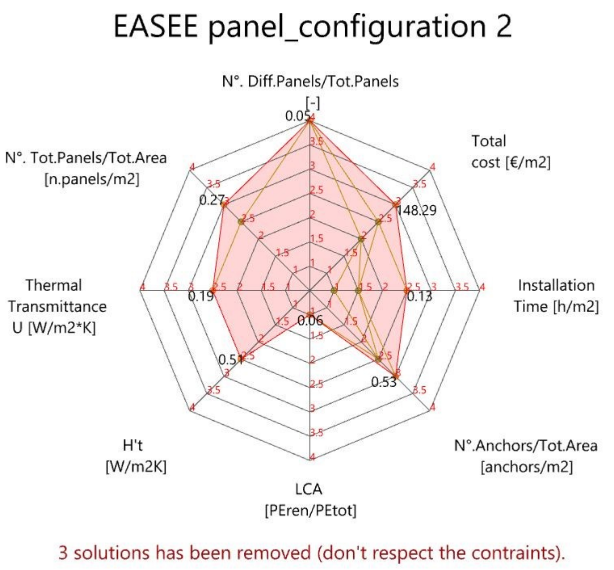
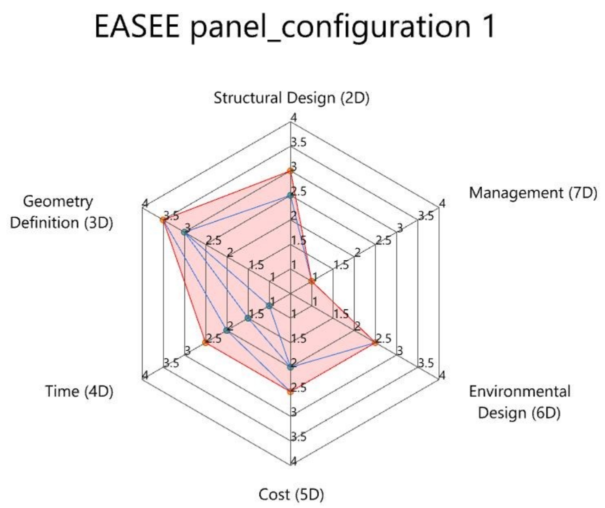


Figure 5.27_ EASEE diagram 2 - in red the best solution for "N°.Tot. panels/Tot. Area" for initial case study (left) VS for the new model (right).



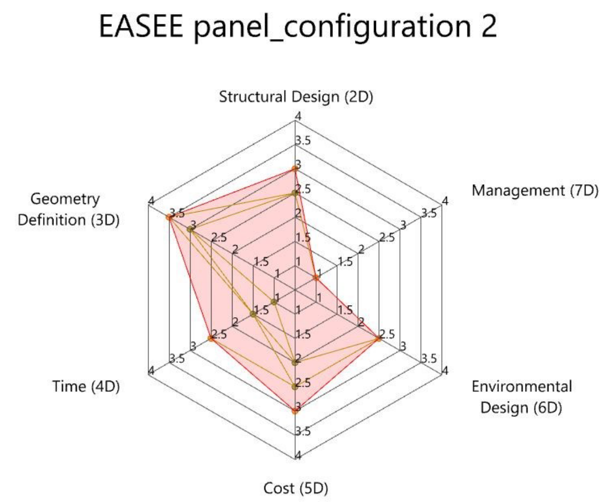


Figure 5.26_ EASEE diagram 3 - in red the best solution for "N°.Tot. panels/Tot. Area" for initial case study (left) VS for the new model (right).

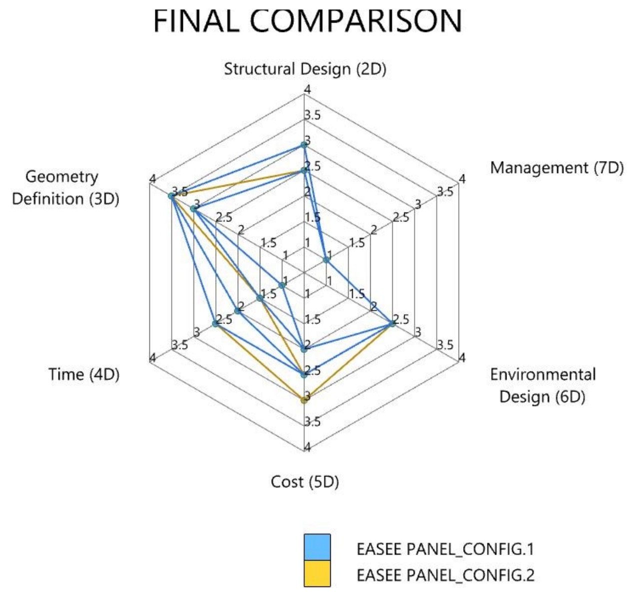


Figure 5.28_ Final comparison - All the possible solutions that respect the constraints.

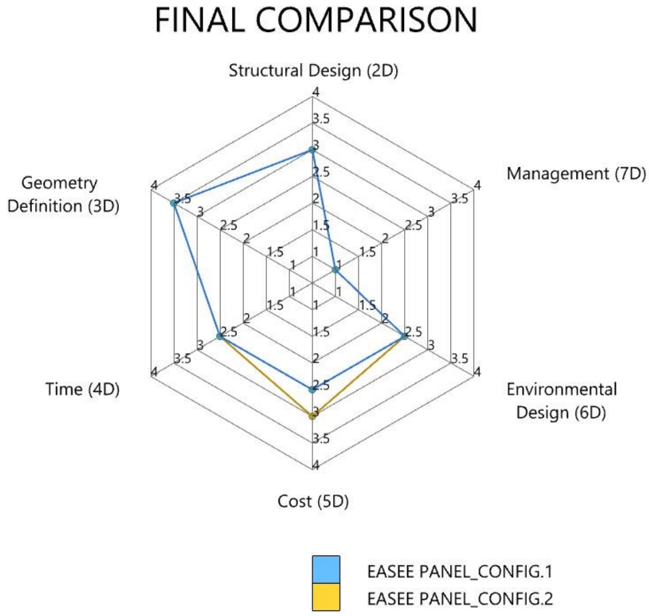


Figure 5.29_ Final Comparison - best solutions for "N°.Tot. panels/Tot. Area".

The comparison of the results obtained by renovating the façade of two different buildings may seem senseless (considering that even the initial situation of the two buildings is already different); however, it was interesting for us to analyse the results in the diagrams we developed to test whether the normalization of the parameters was adequate or not.

What we can deduce from the results is that the intervention on the facade of our second case study would bring better results in terms of energy performance and costs (see *Figure 5.29*).

Taking advantage of the information reported also in the previous diagrams, we note that:

- In "N°. Total Panels/Total Area", the two case studies have the same rating (3 points), but the second building has a value of 0.27 [n.panels/m^2], against 0.30 [n.panels/m^2] of the first case study. This means that comparing the number of panels with the total square meters of the respective buildings, in the second case study we have panels of average size larger.
- In "H't", we note how the second building has better performances (not significantly). This was to be expected due to the fact that we have greatly reduced the number of window surfaces (windows and French doors), removed loggias and a stairwell.
- In "N°. Anchors/Tot. Area", we have further confirmation of the fact that the number of panels in the second case study is lower, due to the fact that overall, we have fewer anchors.
- In "Installation time", we can see how the time required to install the panels is almost the same for the two cases. In fact, the two configurations achieved the same score of 2.5.
- Finally, in "Total cost", we note how the cost per square meter for the renovation of the facade in the second case study is lower than in the first. This allowed it to obtain a rating of half a point higher than the first.

6. CONCLUSION

We have therefore come to an end.

6.1 Achievements

The work we have tried to do (before) and to describe (later) can be said to be **complete**, in the sense that *we have able to answer the questions we asked ourselves at the beginning of the work*.

The proposed tool, in fact, manages to concentrate within it all that series of **3÷7 D parameters** (Geometry modelling, Time programming, Cost evaluation, Performance analysis, Operational management) which was considered to be important in an early-stage design phase. It is therefore characterized by its nature by strong flexibility of use, as it is possible to analyze several aspects at the same time, choosing from time to time on which performance in order to focus one's design choices.

To achieve this, it was essential to precede everything with a study as careful and detailed as possible on the **State of the Art**, both in general and specific terms in the field of **prefabrication**. If on the one hand, in fact, the real extent of the impact of the construction sector of constructions for energy and resource consumption, the age of the European building stock, the market trend of the construction sector, etc. have been understood, on the other hand, it was fundamental to understand how this field is actually unwilling to accept innovations and from which and to what extent the new approaches could benefit the complex. The **Modern Method of Construction** (MMC) processes, born from the combination of the concepts of **Design for Manufacturing and Assembly** (DfMA) and the **Building Information Modeling** (BIM) workflow, has been studied in more depth to understand their real potential and application limits.

Moreover, this tool was also born as a response to and on the basis of the European research call **Building Information Modeling for Energy-Efficient Buildings** (BIM4EEB), which aims to introduce the concepts of improved management of geometric information models for the purpose of improving performance. energetic. it is in this context that our choices have been guided. Joining this project has allowed us to draw on the Italian case study, located in the municipality of Monza.

This allowed us to have a **BIM model** for comparison and on which to reason, also in view of a possible extension of the tool itself to other buildings with similar characteristics. This model, as well as the **Excel** file for data entry, analysis and development, constitute the inputs for the working file in a parametric environment and dictate the import and processing logic.

It is in this work environment, in fact, that we went to carry out all that series of analyzes that led us to evaluate the parameters mentioned at the beginning of this chapter. Wanting to broaden the discussion a little, we list the approaches for each one, remembering that the solutions on which we focused concern the *ETICS*, *EASEE* and *TES Energy Facade* technology.

A very first approach was made in terms of **thermal transmittance** and verification of **hygrothermal behaviour**. As we said before, in fact, the poor performance of buildings in these terms is one of the preponderant factors in energy waste and it was unthinkable not to intervene with external thermal insulation and evaluation of this.

We then moved on to an analysis of the **geometric definition** of what are the surfaces subject to intervention, addressed system by system, each with its own founding logics. The importance of this phase is crucial, as it determines all subsequent aspects by weight of each panel, length of thermal bridges, etc. as well as management of the **LABEL** to be assigned to each element for the transmissible information flow part.

We then moved on to an analysis involving the structural aspects of the individual panels, evaluated with qualitative considerations in terms of the number of **anchors necessary** to support the element and the deformation obtained under the effect of the applied loads. More than a verification for its own sake, we tried to probe the possibilities of making considerations on these issues in the *parametric field* and/or on other software which can be related to this environment.

We then returned to the global energy aspects, analyzing at this point the **Global Average Heat Exchange Coefficient** H'_T, taken as a reliable index of overall analysis on the whole building. In fact, all the data mentioned above are included here, both in terms of two-dimensional and one-dimensional thermal transmittance and quantification of areas and edges.

Finally, more for the desire to test the limits of the tool than for the need to carry out this kind of analysis, we tried to integrate the concepts of **Time**, **Cost** and **Management** within the final graph. As we said, *they occupy a marginal space in this discussion and certainly should be analyzed more in-depth to constitute a reliable parameter*, but their presence testifies to how much and how the analyzes can also be extended to fields that are usually considered little and not in holistic management of the process, which we have focused on since the beginning.

In conclusion, we have therefore exposed the **export potential** of this analysis, to ensure that it does not remain confined to a parametric modelling environment, still little known and usable by most.

The first possibility of visualization resides in the **Design Explorer** tool by CORE Studio | Thornton Tomasetti, which through the use of graphics and images that are captivating in terms of quantity of information and graphic quality, allow users to make reasoned choices based on **Design Optioneering** (DO), by subjects more or less competent in these areas. Alongside this visualization, it was decided to graphically represent the results in a process summary **Spider Diagram**, which would show on the screen all the options with assigned numerical evaluation. Reading an image can therefore be even simpler but still influential in the choice phase.

Finally, alongside the **export** of the results, it was decided to show how it is possible to return **to** the **BIM** environment by plotting the chosen solutions both for geometries (Panels) and for information (Catalogue), closing the circle of BIM design and providing real support and concrete to three-dimensional designers.

6.2 Future Developments

There are some unfinished aspects that we hope to be able to deepen in the future.

The first observation that we would like to make concerns the **management of the 3D Model**. As we have tried to explain several times, everything works both on the case study and on a model derived from that, which have heavy modification (this has been proven with images and descriptions in the text). However, it must be said that the **three-dimensional models are all different from each** other and that therefore changing the completion of the reference building can change the logic with which this model was built; therefore, the export is not so precise, causing errors in the script. In our opinion, the level and degree of in-depth analysis are still good and, in this sense, it would be interesting to draw up a **check-list** of convergence **requirements** between 3D Revit modelling and export logics that can truly make this delicate phase clear. *It does not, therefore, represent a limit to the level of development we had set for ourselves and it does not represent an insurmountable obstacle in general, it simply needs more attention.*

Another aspect certainly to be re-evaluated is the **degree of depth of some analyzes** that have been carried out. For example, *it was not our intention to draw up an analytical procedure* that could be assimilated to the structural verification of a prefabricated panel and therefore the level of detail did not go as far. Similar speeches could be made regarding the thematic areas of Time, Cost and Management, on which it is strongly recommended to focus more when the goal becomes to find exact estimates. Even in this case, however, the limits are mainly due to the purposes we set out to achieve. Case by case, however, we have still tried to leave holds to which we can grasp in the event that more sensible values are provided; first of all the possibility of **interoperability with the Excel sheet**, which communicates very well with a parametric environment like ours. *Therefore, by inserting a "more correct" value in a specific cell, it is very easy to draw on this source and insert this "number" in the final comparative diagrams, instead of those identified by us.*

Finally, the flow of **exporting geometries to a BIM environment** such as Revit could be greatly improved, also taking advantage of the growing interest in this sector. New possibilities are emerging month after month so it is realistic to think that this can evolve profoundly in the very short term. However, it remains important to underline that the process must be guided by the purpose it intends to pursue and that it is, therefore, important to agree immediately on what you intend to export in terms of geometry and information. *Nothing impossible, therefore, as in other cases, an extra level of in-depth analysis is simply required.*

ANNEX A

This annex reports, in more detail, the study carried out on the chosen solution:

External Thermal Insulation Composite System (ETICS)

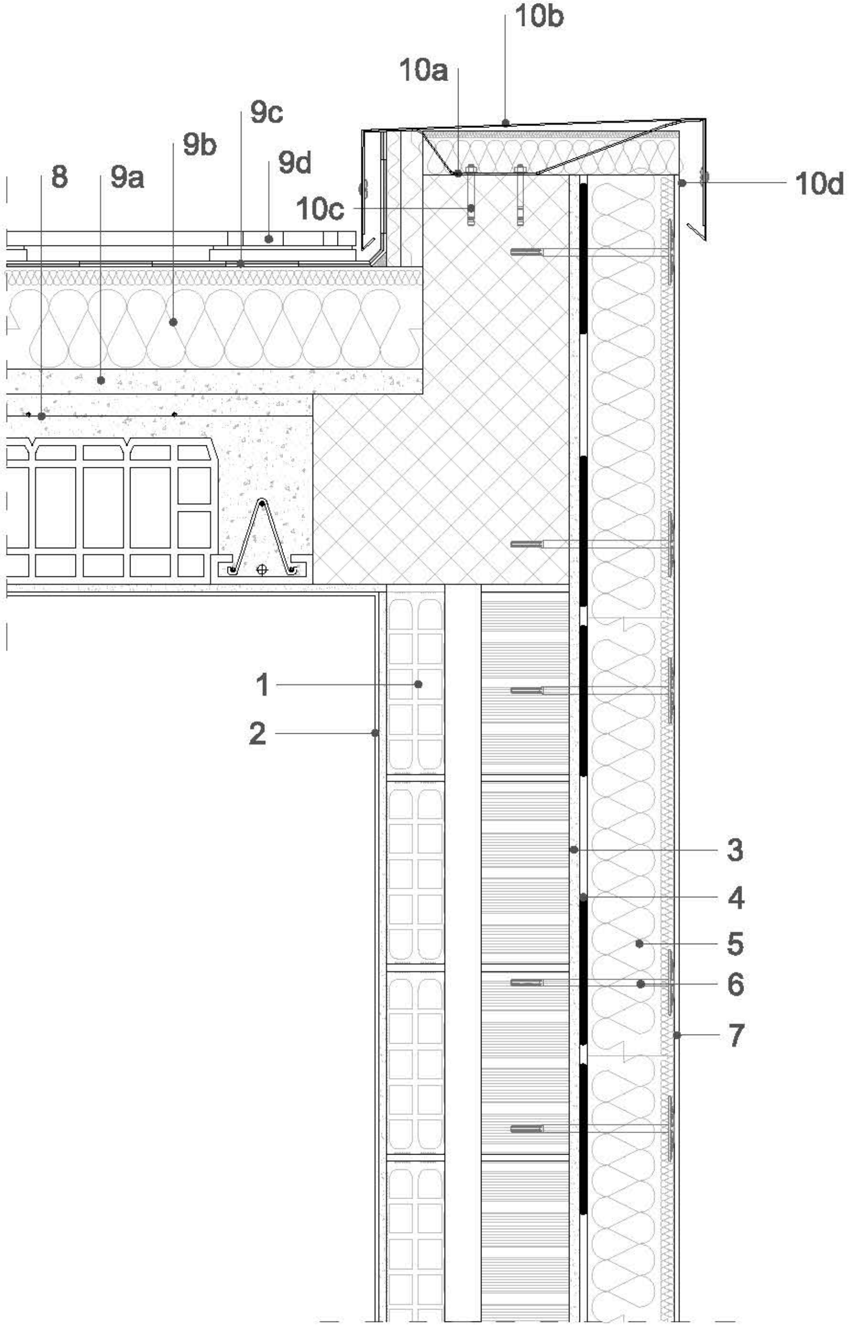
The nodes studied - and therefore developed - must not be understood as executive drawings of the solution itself but are examples of the peculiarities that this solution entails.

They are therefore suitable for understanding both the stratigraphy package, but also and above all the interfaces and this solution in specific points of the construction.

Specifically, the following were analyzed (scale 1:10):

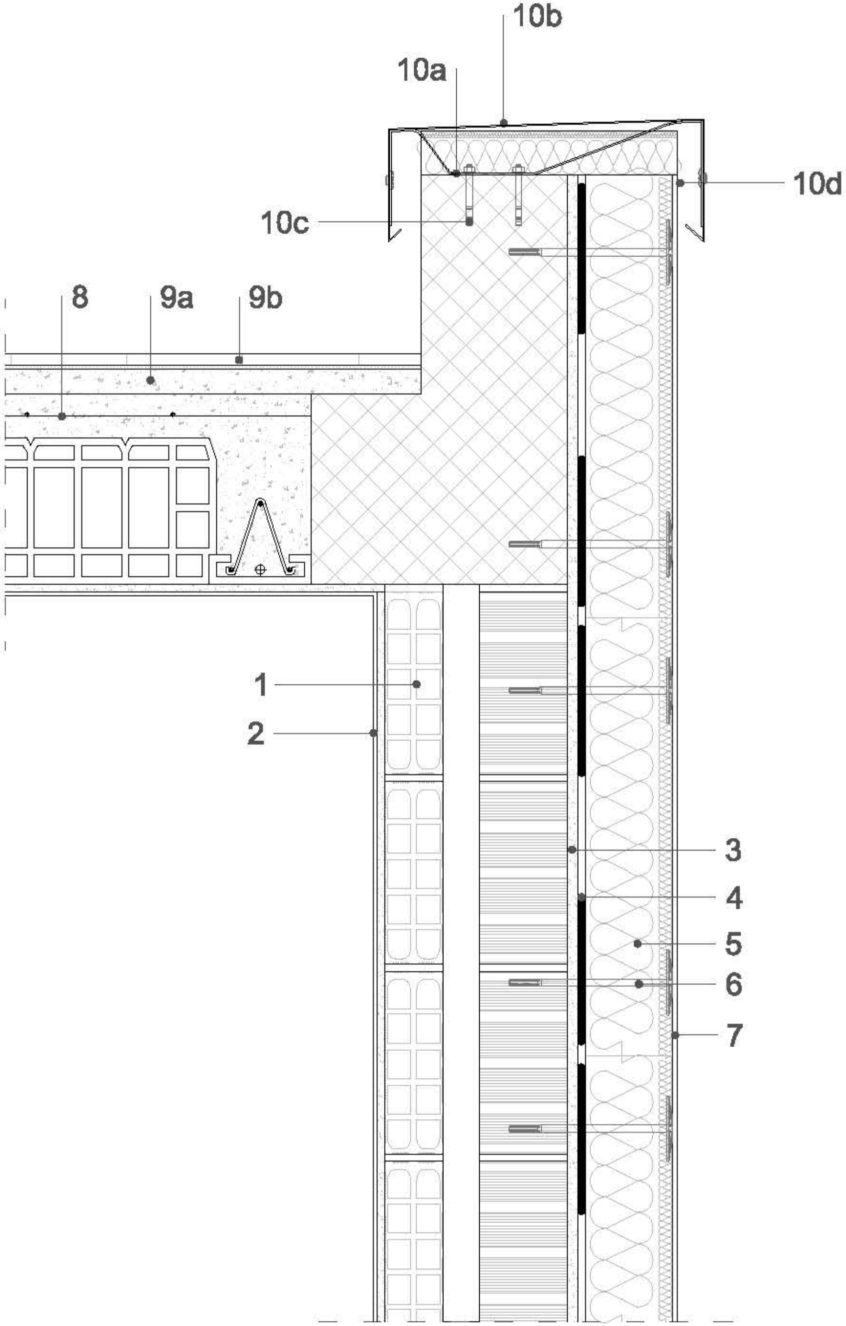
- **A.1** **vertical section: covering with roof refurbishment**;
- **A.2** **vertical section: covering with no roof refurbishment**;
- **A.3** **vertical section: inter-floor**;
- **A.4** **vertical section: basement**;
- **A.5** **horizontal section: panel-panel**;
- **A.6** **horizontal section: panel-panel corner**;
- **A.7** **vertical section: top window**;
- **A.8** **vertical section: bottom window**;
- **A.9** **horizontal section: side window**.

A.1



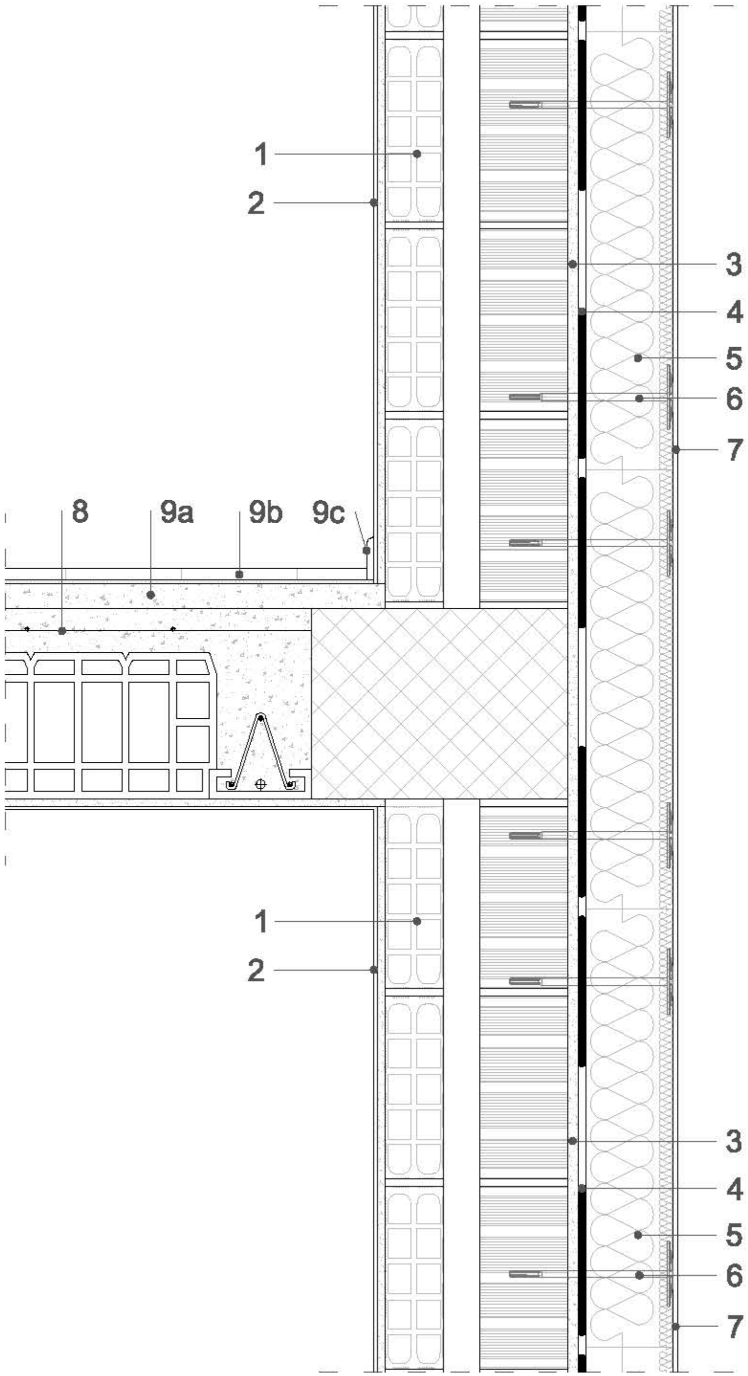
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
6. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
7. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo, sp. 3.5 cm (a) + Pannello rigido in lana di roccia ad alta densità, calpestabile, sp. 12.0 cm, λ = 0.038 W/m^2K, d = 148 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0 (b) + Doppio strato di tenuta all'acqua in membrana bituminosa elastomerica armata in TNT poliestere e membrana bituminosa elastomerica antiradice in TNT poliestere (c) + Piedini in polipropilene per pavimento sopraelevato esterno e pannelli di calpestio (d);
10. Staffa di sostegno in alluminio sagomato ad U (a) + Scossalina di tenuta all'acqua, sp. 15/10 mm, pendenza del 1.5% (b). Fissaggio al supporto tramite tassello meccanico a espansione per calcestruzzo, Ø = 8 mm, lungh. = 85 mm (c); Rivetto a farfalla per il fissaggio della scossalina alla staffa di sostegno (d).

A.2



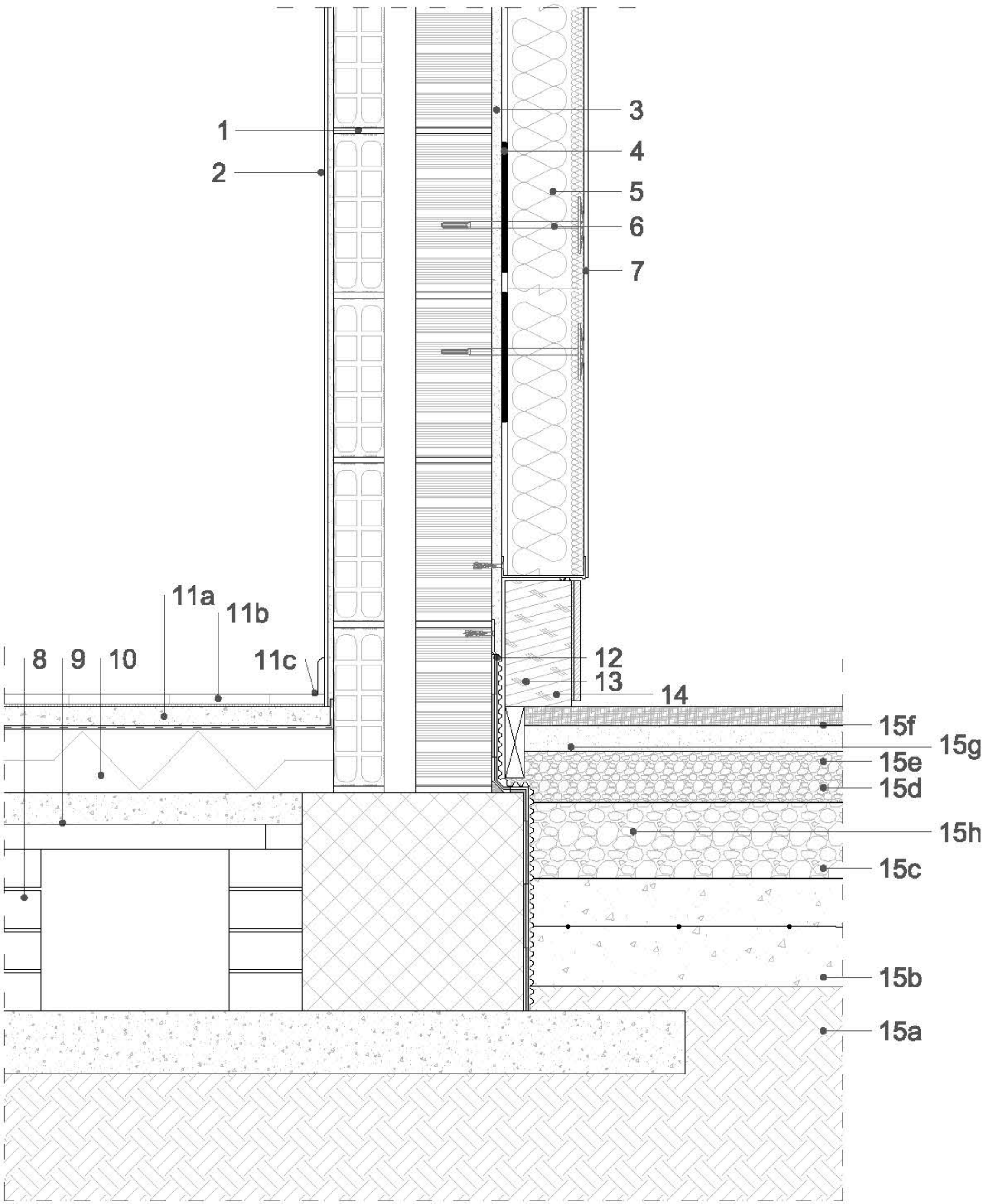
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
6. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
7. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo, sp. 3.5 cm (a) + Pannello rigido in lana di roccia ad alta densità, calpestabile, sp. 12.0 cm, λ = 0.038 W/m^2K, d = 148 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0 (b) + Doppio strato di tenuta all'acqua in membrana bituminosa elastomerica armata in TNT poliestere e membrana bituminosa elastomerica antiradice in TNT poliestere (c) + Piedini in polipropilene per pavimento sopraelevato esterno e pannelli di calpestio (d);
10. Staffa di sostegno in alluminio sagomato ad U (a) + Scossalina di tenuta all'acqua, sp. 15/10 mm, pendenza del 1.5% (b).
    Fissaggio al supporto tramite tassello meccanico a espansione per calcestruzzo, Ø = 8 mm, lungh. = 85 mm (c); Rivetto a farfalla per il fissaggio della scossalina alla staffa di sostegno (d).

A.3



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
6. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
7. Soletta latero-cementizia, sp. 30 cm;
8. Strato di sottofondo, sp. 3.5 cm (a) + Pavimentazione, sp. 2.0 cm (b) + Zoccolino (c).

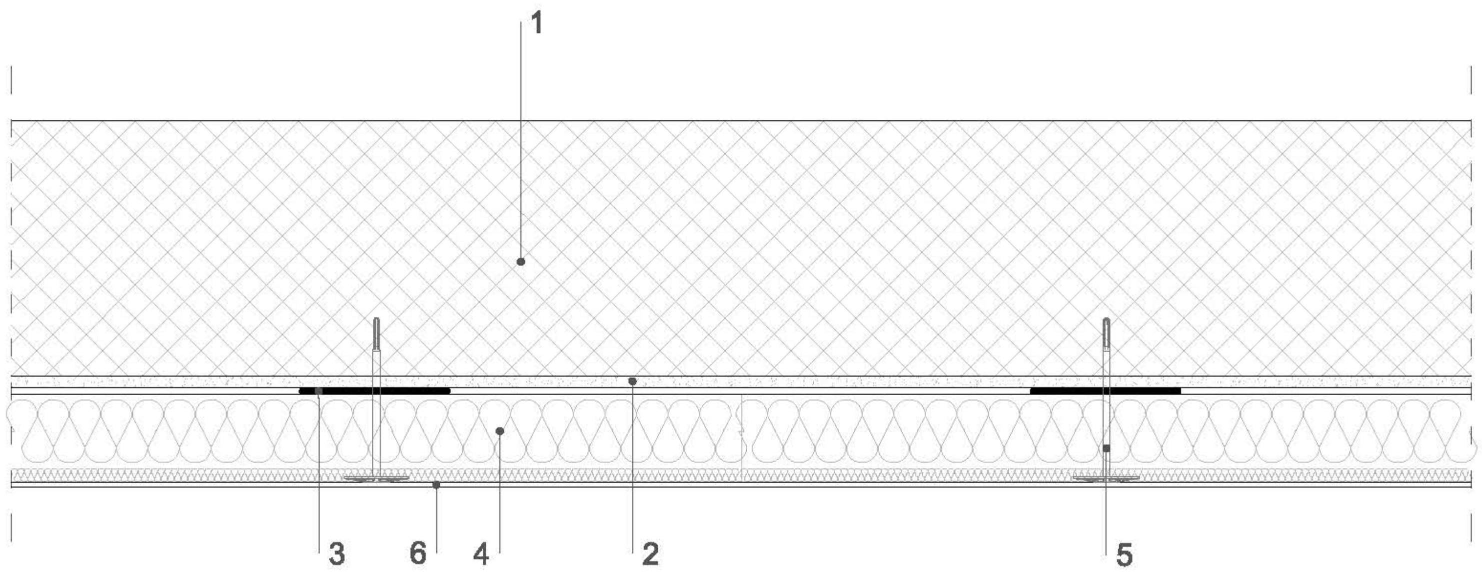
A.4



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1,5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
6. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
7. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
8. Vespaio areato in tavelle di laterizio, sp. 4.0 cm, d = 350 kg/m^3;
9. Strato di posa e regolarizzazione del piano di posa / carichi applicati, realizzato in in calcestruzzo armato, sp. 5.0 cm;
10. Pannelli isolanti in polistirene espanso (EPS), sp. 10.0 cm, λ = 0.042 W/m^2K, d = 25 kg/m^3, calore specifico = 1400 J/kgK, classe di reazione al fuoco E;
11. Strato di sottofondo, sp. 3.5 cm (a), Pavimentazione, sp. 2.0 cm (b) + Zoccolino (c);
12. Sistema di impermeabilizzazione alla base dell'edificio, costituito da membrana bituminosa contro la risalita dell'umidità;
13. Isolamento termico e strato di protezione alla base dell'edificio, costituito da pannello in polistirene espanso estruso (XPS), sp. = 10 cm, λ = 0.035 W/m^2K, d = 32 kg/m^3, calore specifico = 1700 J/kgK, classe di reazione al fuoco E;
14. Elemento di raccordo e finitura zoccolo edificio;
15. Terreno naturale di riporto (a) + Cappa in calcestruzzo armato (b) + Strato di sottofondo costituito da una miscela di pietrisco e sabbia (c) + Strato di base in conglomerato bituminoso (d) + Strato di collegamento, o binder, in conglomerato bituminoso (e) + Strato di usura (f) + Cordonato in cls prefabbricato (g) + Membrana bugnata in polietilene ad alta densità (HDPE) (h).

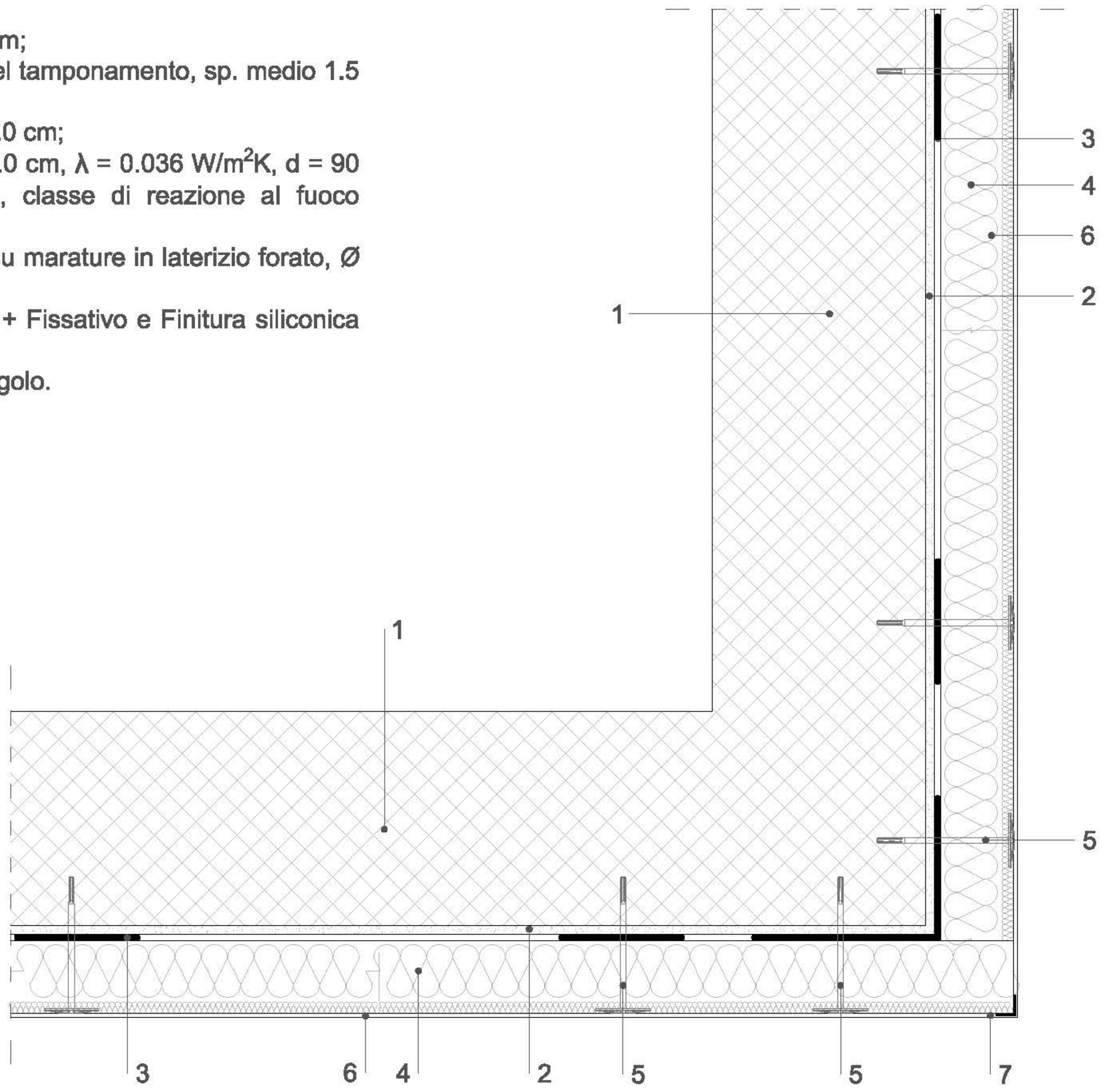
A.5

1. Trave in calcestruzzo armato, sp. 35.0 cm;
2. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
3. Strato collante per cappotti, sp. medio 1.0 cm;
4. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
5. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
6. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);

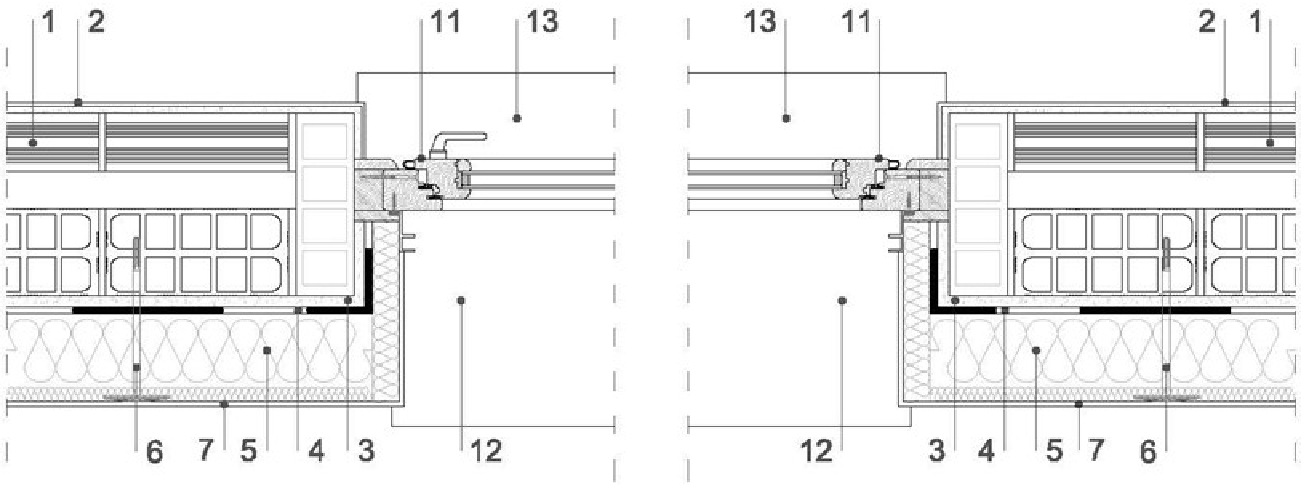


A.6

1. Trave in calcestruzzo armato, sp. 35.0 cm;
2. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
3. Strato collante per cappotti, sp. medio 1.0 cm;
4. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^{2}K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
5. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
6. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
7. Profilo verticale in PVC per rinforzo d'angolo.

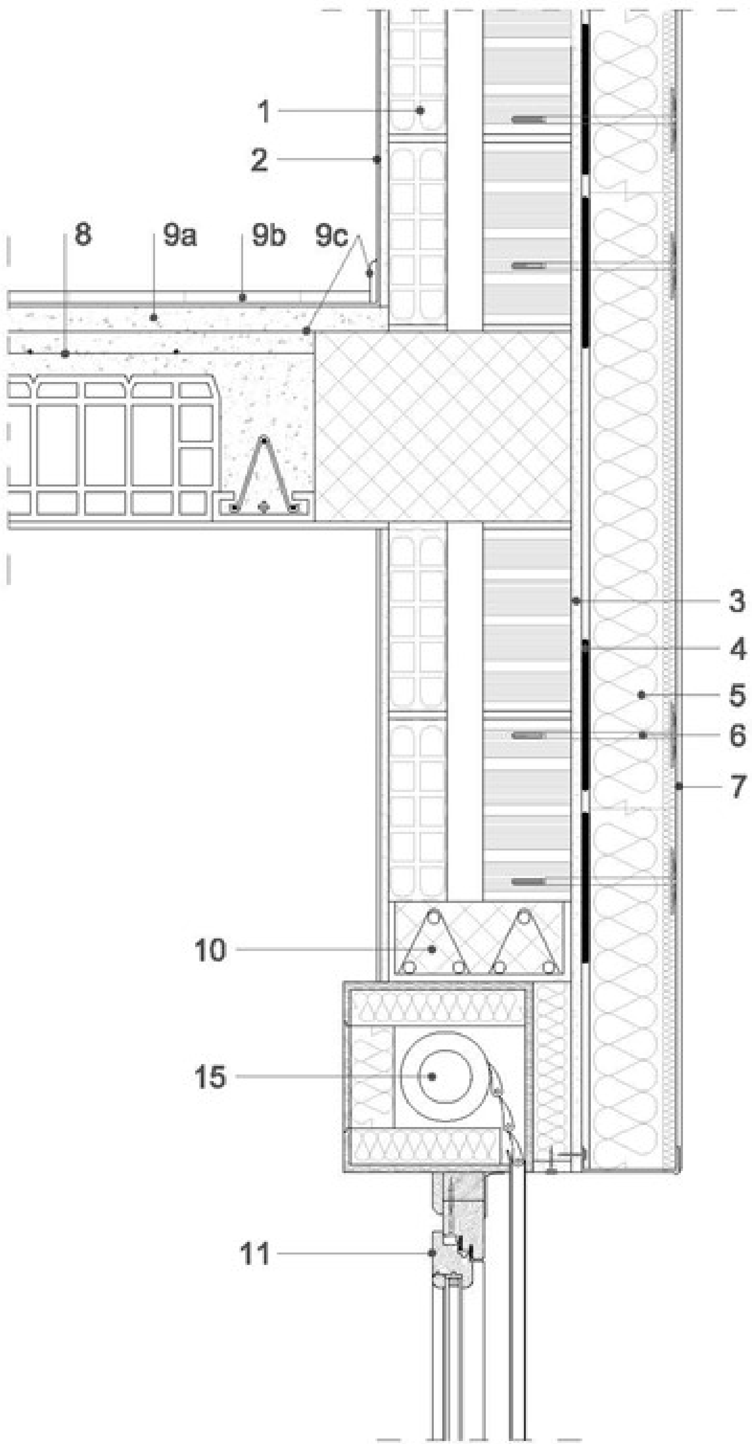


A.7



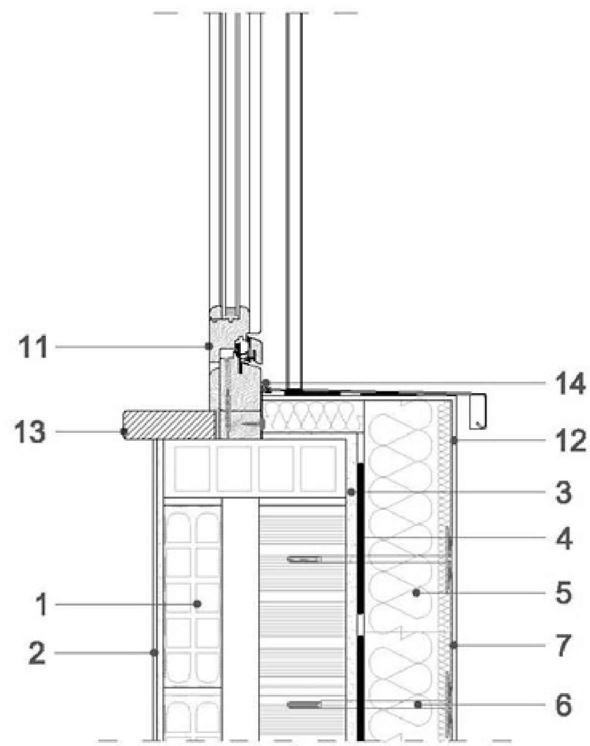
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
6. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
7. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
8. Serramento in legno con vetrocamera;
9. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
10. Davanzale interno in pietra naturale, sp. 4 cm;

A.8



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
6. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
7. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo (sp. 3.5 cm), Pavimentazione (sp. 2.0 cm) e Finiture interne (zoccolino, materassino anti-calpestio, ecc.);
10. Architrave precompresso in laterocemento, dim. 25.0 x 12.0 cm;
11. Serramento in legno con vetrocamera;
12. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
13. Davanzale interno in pietra naturale, sp. 4 cm;
14. Sigillatura interfaccia cappotto - serramento;
15. Cassonetto in PVC coibentato + sistema di oscuramento con avvolgibile.

A.9



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Intonaco di regolarizzazione e finitura del tamponamento, sp. medio 1.5 cm;
4. Strato collante per cappotti, sp. medio 1.0 cm;
5. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.036 W/m^2K, d = 90 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
6. Tassello per fissaggio pannelli isolanti su marature in laterizio forato, Ø = 10 mm, lungh. = 200 mm, (posa a W);
7. Strato di rasatura armata (sp. 5.0 mm) + Fissativo e Finitura siliconica (sp. 1.5 mm);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo (sp. 3.5 cm), Pavimentazione (sp. 2.0 cm) e Finiture interne (zoccolino, materassino anti-calpestio, ecc.);
10. Architrave precompresso in laterocemento, dim. 25.0 x 12.0 cm;
11. Serramento in legno con vetrocamera;
12. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
13. Davanzale interno in pietra naturale, sp. 4 cm;
14. Sigillatura interfaccia cappotto - serramento;
15. Cassonetto in PVC coibentato + sistema di oscuramento con avvolgibile.

ANNEX B

This annex reports, in more detail, the study carried out on the chosen solution:

EASEE research (Envelope Approach to improve Sustainability and Energy efficiency in Existing multi-storey, multi-owner residential buildings).

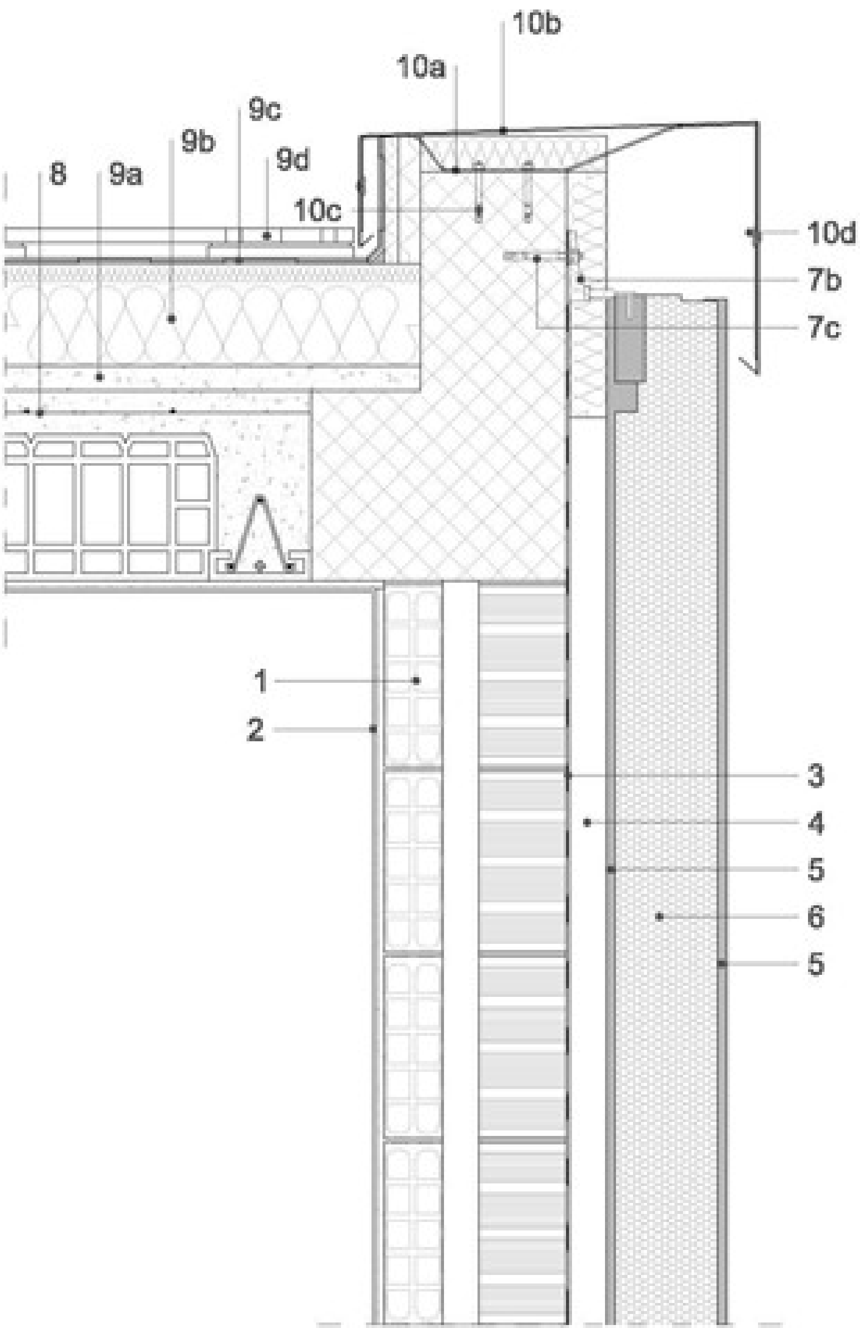
The nodes studied - and therefore developed - must not be understood as executive drawings of the solution itself but are examples of the peculiarities that this solution entails.

They are therefore suitable for understanding both the stratigraphy package, but also and above all the interfaces and this solution in specific points of the construction.

Specifically, the following were analyzed (scale 1:10):

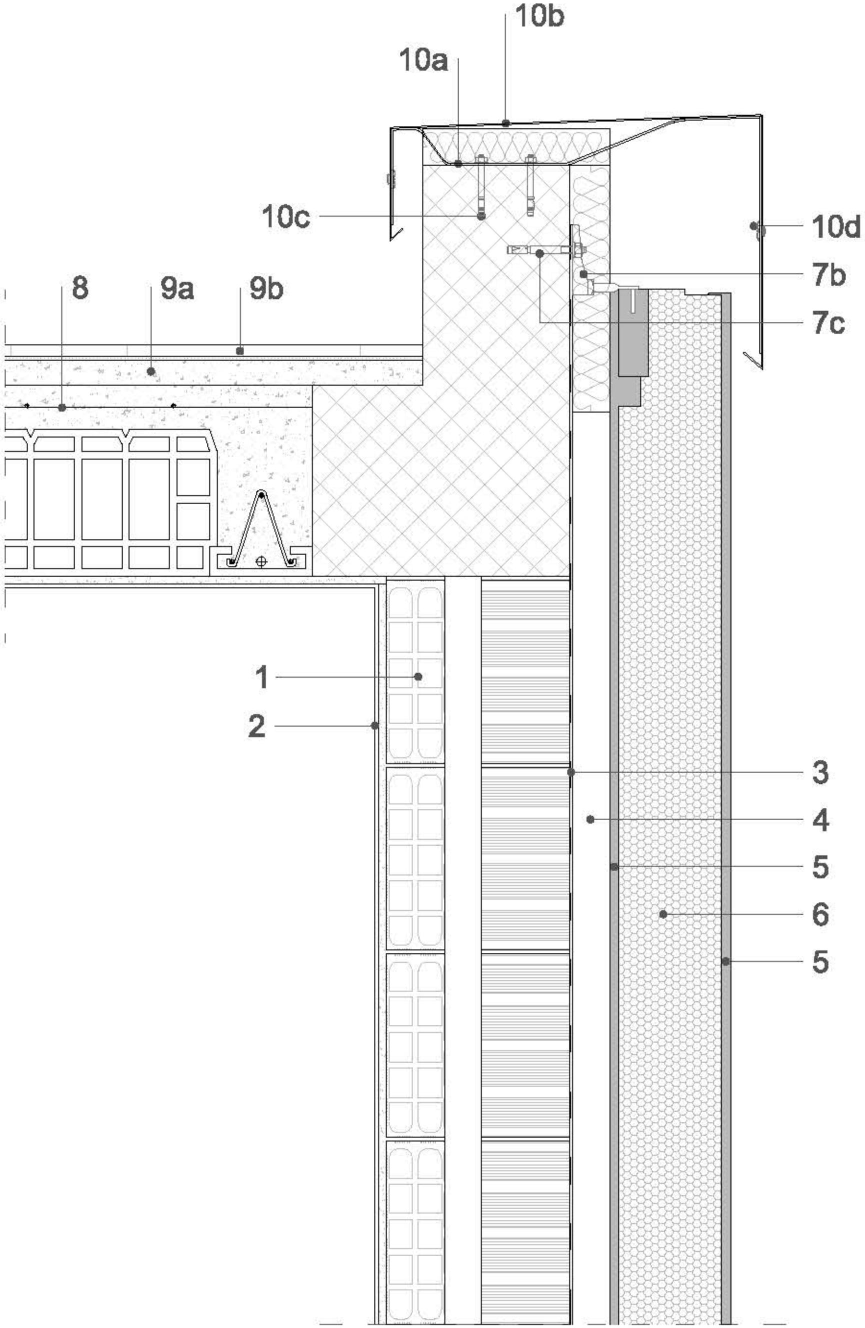
- **B.1 vertical section: covering with roof refurbishment**;
- **B.2 vertical section: covering with no roof refurbishment**;
- **B.3 vertical section: inter-floor**;
- **B.4 vertical section: basement**;
- **B.5 horizontal section: panel-panel**;
- **B.6 horizontal section: panel-panel corner (45°)**;
- **B.7 horizontal section: panel-panel corner (90°)**;
- **B.8 vertical section: top window**;
- **B.9 vertical section: bottom window**;
- **B.10 horizontal section: side window**.

B.1



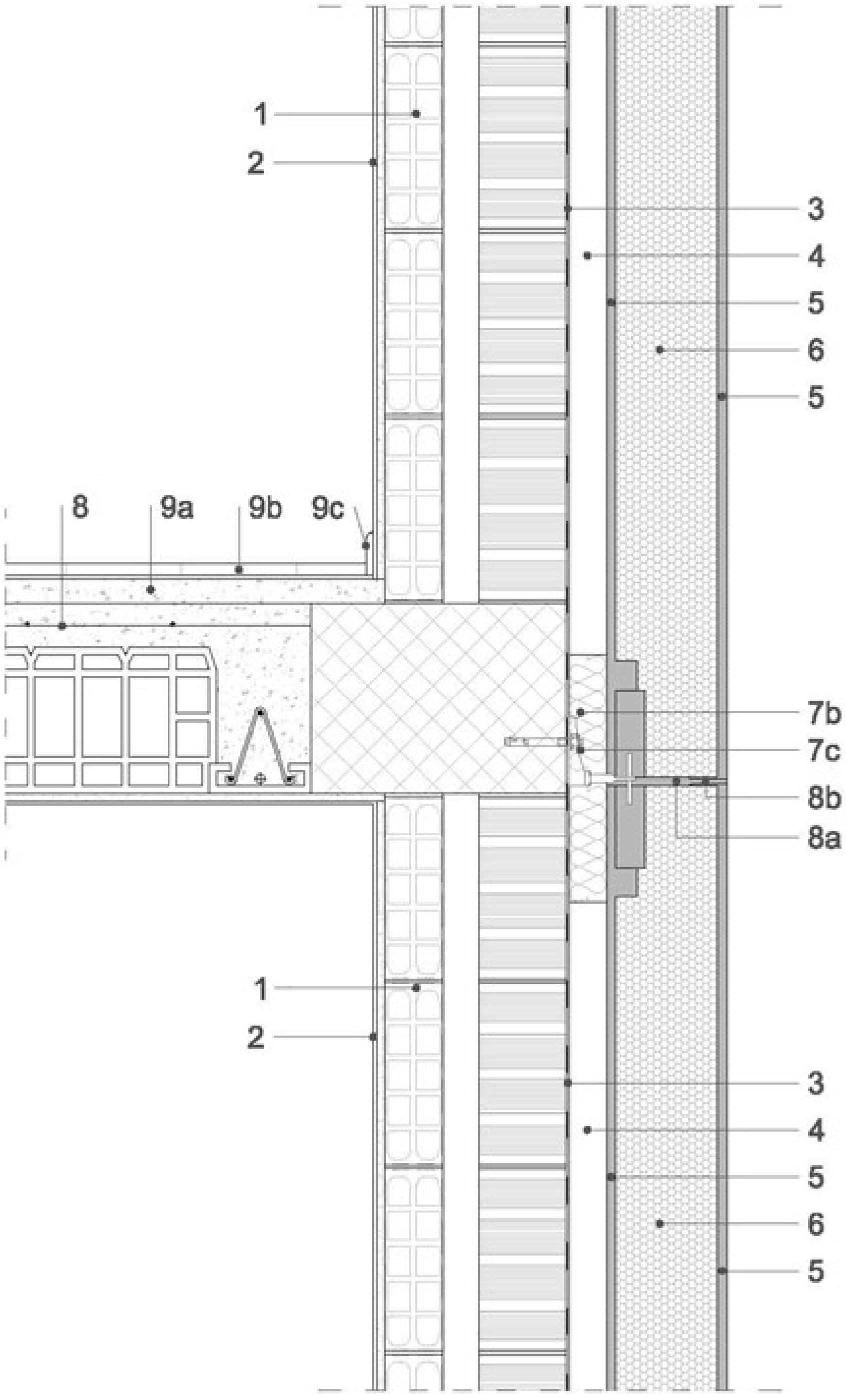
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 6'666'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1.25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo, sp. 3.5 cm (a) + Pannello rigido in lana di roccia ad alta densità, calpestabile, sp. 12.0 cm, λ = 0.038 W/m^2K, d = 148 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0 (b) + Doppio strato di tenuta all'acqua in membrana bituminosa elastomerica armata in TNT poliestere e membrana bituminosa elastomerica antiradice in TNT poliestere (c) + Piedini in polipropilene per pavimento sopraelevato esterno e pannelli di calpestio (d);
10. Staffa di sostegno in alluminio sagomato ad U (a) + Scossalina di tenuta all'acqua, sp. 15/10 mm, pendenza del 1.5% (b). Fissaggio al supporto tramite tassello meccanico a espansione per calcestruzzo, Ø = 8 mm, lungh. = 85 mm (c); Rivetto a farfalla per il fissaggio della scossalina alla staffa di sostegno (d).

B.2



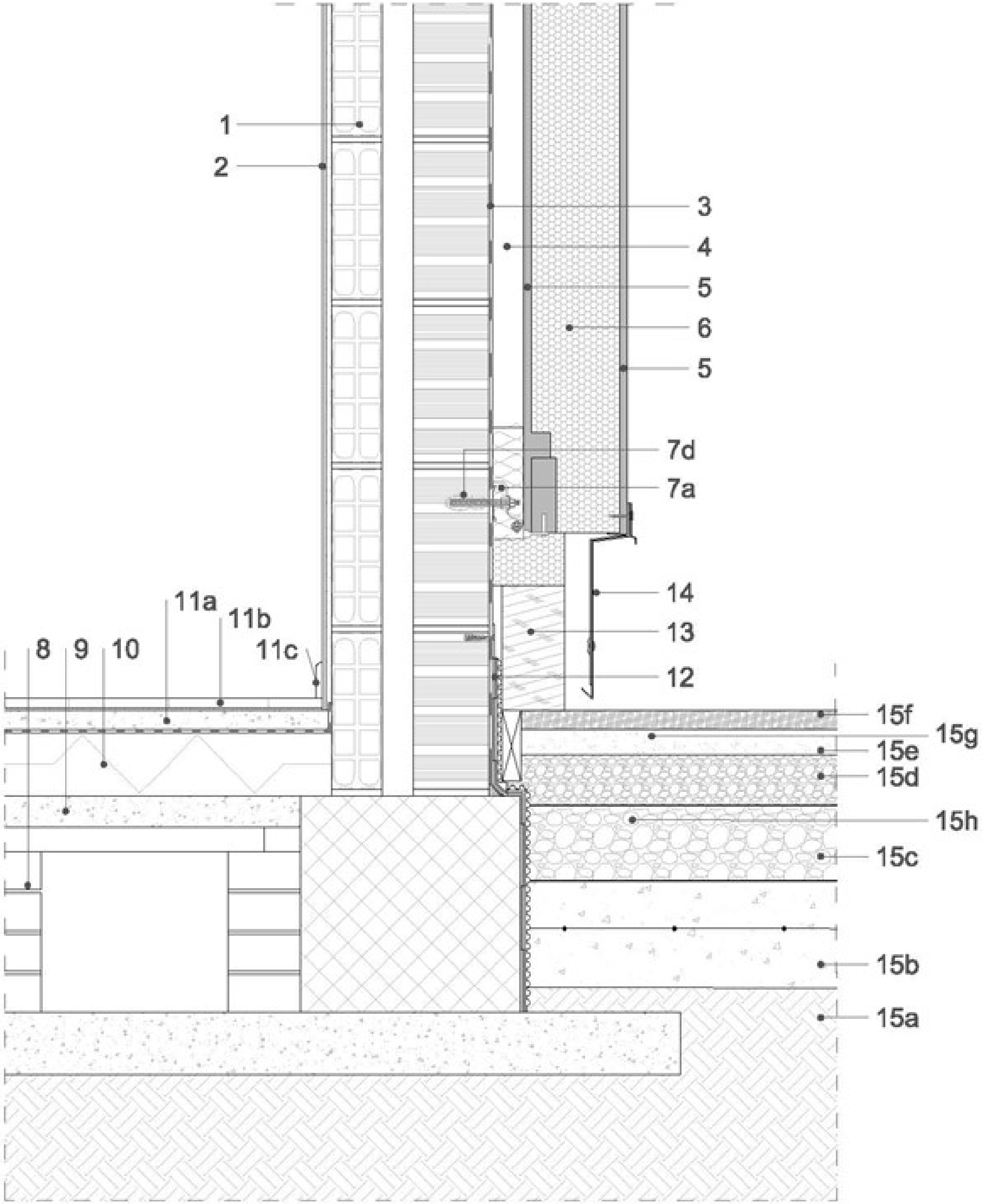
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 6'666'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1.25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Soletta latero-cementizia, sp. 30 cm;
11. Strato di sottofondo, sp. 3.5 cm (a) + Piano di calpestio in piastrelle incollate al sottofondo, sp. 2,0 cm (b);
12. Staffa di sostegno in alluminio sagomato ad U (a) + Scossalina di tenuta all'acqua, sp. 15/10 mm, pendenza del 1.5% (b). Fissaggio al supporto tramite tassello meccanico a espansione per calcestruzzo, Ø = 8 mm, lungh. = 85 mm (c); Rivetto a farfalla per il fissaggio della scossalina alla staffa di sostegno (d).

B.3



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1.25 cm, $\lambda = 2.0\ W/m^2K$, $d = 2311\ Kg/m^3$, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, $\lambda = 0.037\ W/m^2K$, $d = 15\ kg/m^3$, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Fondogiunto in polietilene (a) + Sigillante siliconico acrilico a basso modulo di elasticità (b);
9. Soletta latero-cementizia, sp. 30 cm;
10. Strato di sottofondo, sp. 3.5 cm (a) + Pavimentazione, sp. 2.0 cm (b) + Finiture interne (zoccolino, materassino anti-calpestio, ecc.) (c).

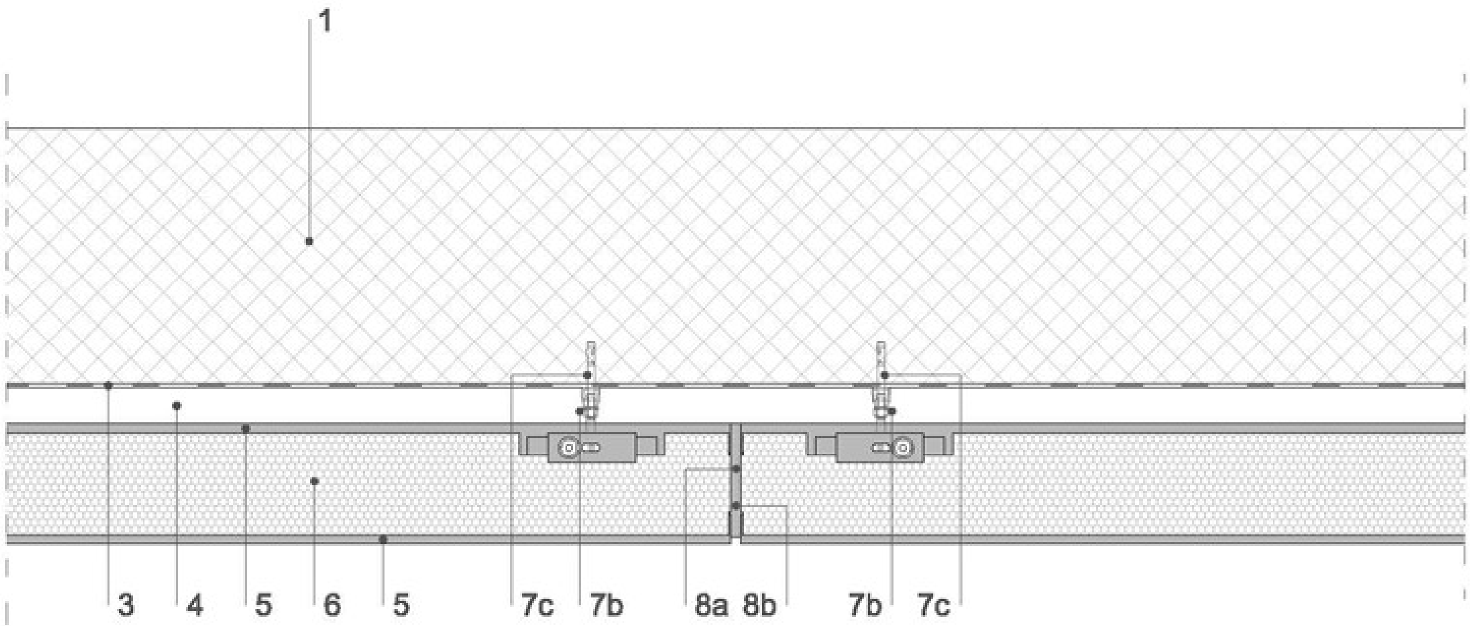
B.4



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1.25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Ancorante chimico ad alte prestazioni per fissaggi su muratura, Ø = 8.0 mm, lungh. = 105 mm (d);
8. Vespaio areato in tavelle di laterizio, sp. 4.0 cm, d = 350 kg/m^3;
9. Strato di posa e regolarizzazione del piano di posa / carichi applicati, realizzato in in calcestruzzo armato, sp. 5.0 cm;
10. Pannelli isolanti in polistirene espanso (EPS), sp. 10.0 cm, λ = 0.042 W/m^2K, d = 25 kg/m^3, calore specifico = 1400 J/kgK, classe di reazione al fuoco E;
11. Strato di sottofondo, sp. 3.5 cm (a), Pavimentazione, sp. 2.0 cm (b) + Zoccolino (c);
12. Sistema di impermeabilizzazione alla base dell'edificio, costituito da membrana bituminosa contro la risalita dell'umidità;
13. Isolamento termico e strato di protezione alla base dell'edificio, costituito da pannello in polistirene espanso estruso (XPS), sp. = 10 cm, λ = 0.035 W/m^2K, d = 32 kg/m^3, calore specifico = 1700 J/kgK, classe di reazione al fuoco E;
14. Elemento di raccordo e finitura zoccolo edificio;
15. Terreno naturale di riporto (a) + Cappa in calcestruzzo armato (b) + Strato di sottofondo costituito da una miscela di pietrisco e sabbia (c) + Strato di base in conglomerato bituminoso (d) + Strato di collegamento, o binder, in conglomerato bituminoso (e) + Strato di usura (f) + Cordonato in cls prefabbricato (g) + Membrana bugnata in polietilene ad alta densità (HDPE) (h).

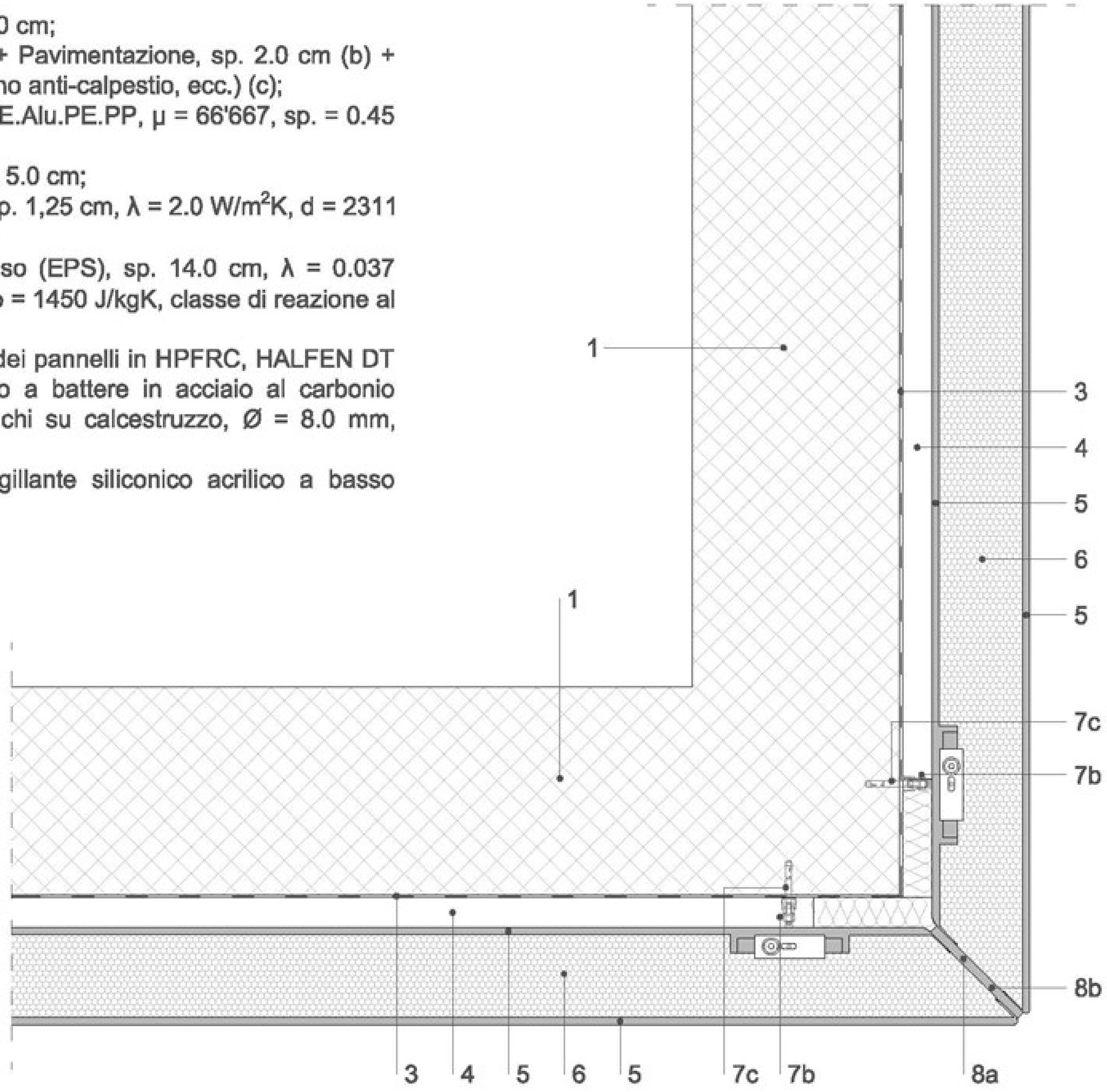
B.5

1. Trave in calcestruzzo armato, sp. 35.0 cm;
2. Strato di sottofondo, sp. 3.5 cm (a) + Pavimentazione, sp. 2.0 cm (b) + Finiture interne (zoccolino, materassino anti-calpestio, ecc.) (c);
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1,25 cm, $\lambda = 2.0\ W/m^2K$, $d = 2311\ Kg/m^3$, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, $\lambda = 0.037\ W/m^2K$, $d = 15\ kg/m^3$, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Fondogiunto in polietilene (a) + Sigillante siliconico acrilico a basso modulo di elasticità (b).



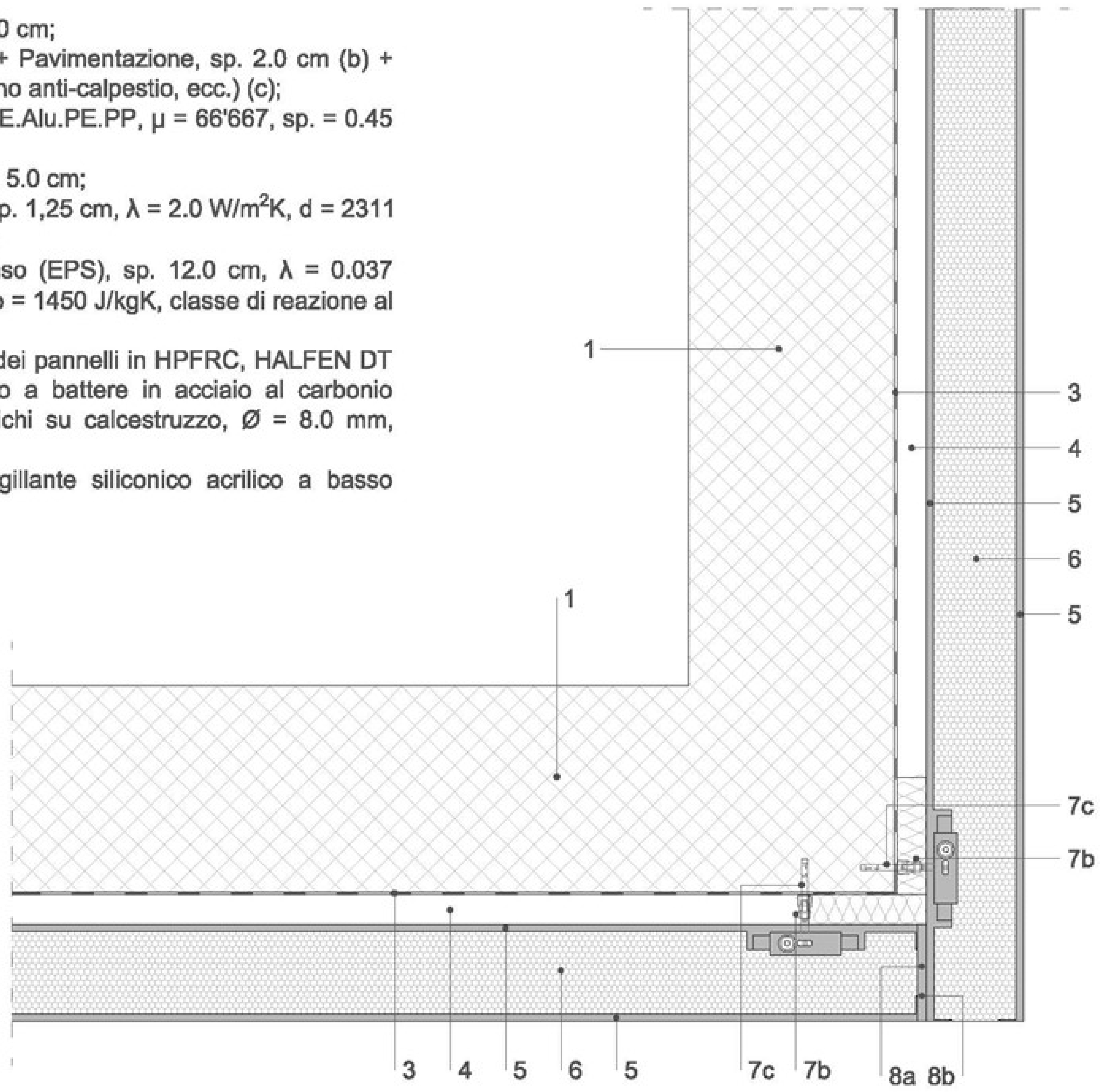
B.6

1. Trave in calcestruzzo armato, sp. 35.0 cm;
2. Strato di sottofondo, sp. 3.5 cm (a) + Pavimentazione, sp. 2.0 cm (b) + Finiture interne (zoccolino, materassino anti-calpestio, ecc.) (c);
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1,25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Fondogiunto in polietilene (a) + Sigillante siliconico acrilico a basso modulo di elasticità (b);

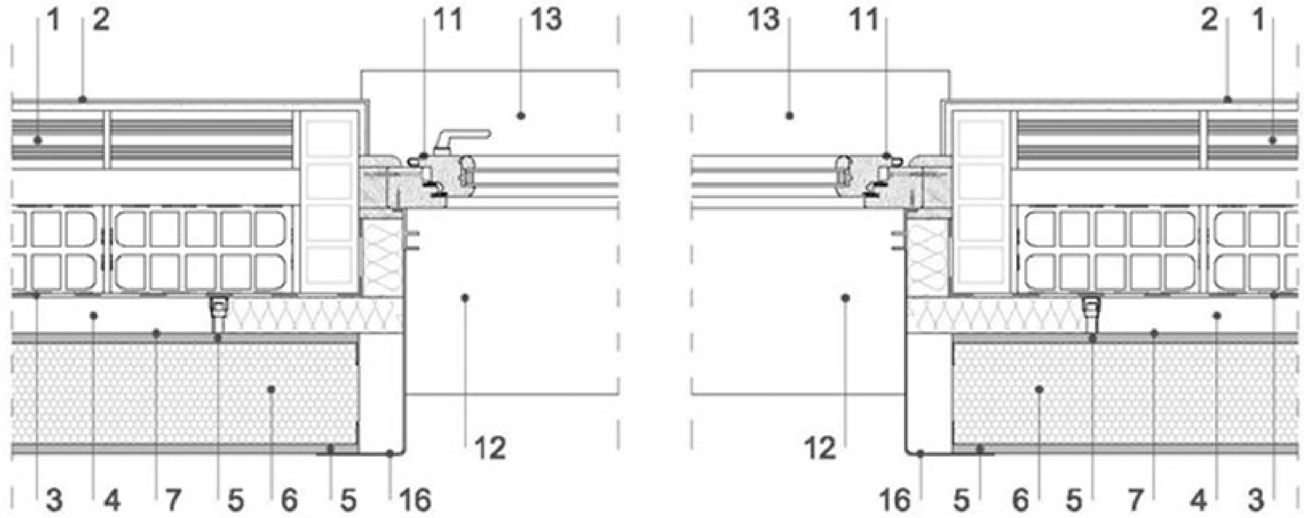


B.7

1. Trave in calcestruzzo armato, sp. 35.0 cm;
2. Strato di sottofondo, sp. 3.5 cm (a) + Pavimentazione, sp. 2.0 cm (b) + Finiture interne (zoccolino, materassino anti-calpestio, ecc.) (c);
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1,25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 12.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Fondogiunto in polietilene (a) + Sigillante siliconico acrilico a basso modulo di elasticità (b);

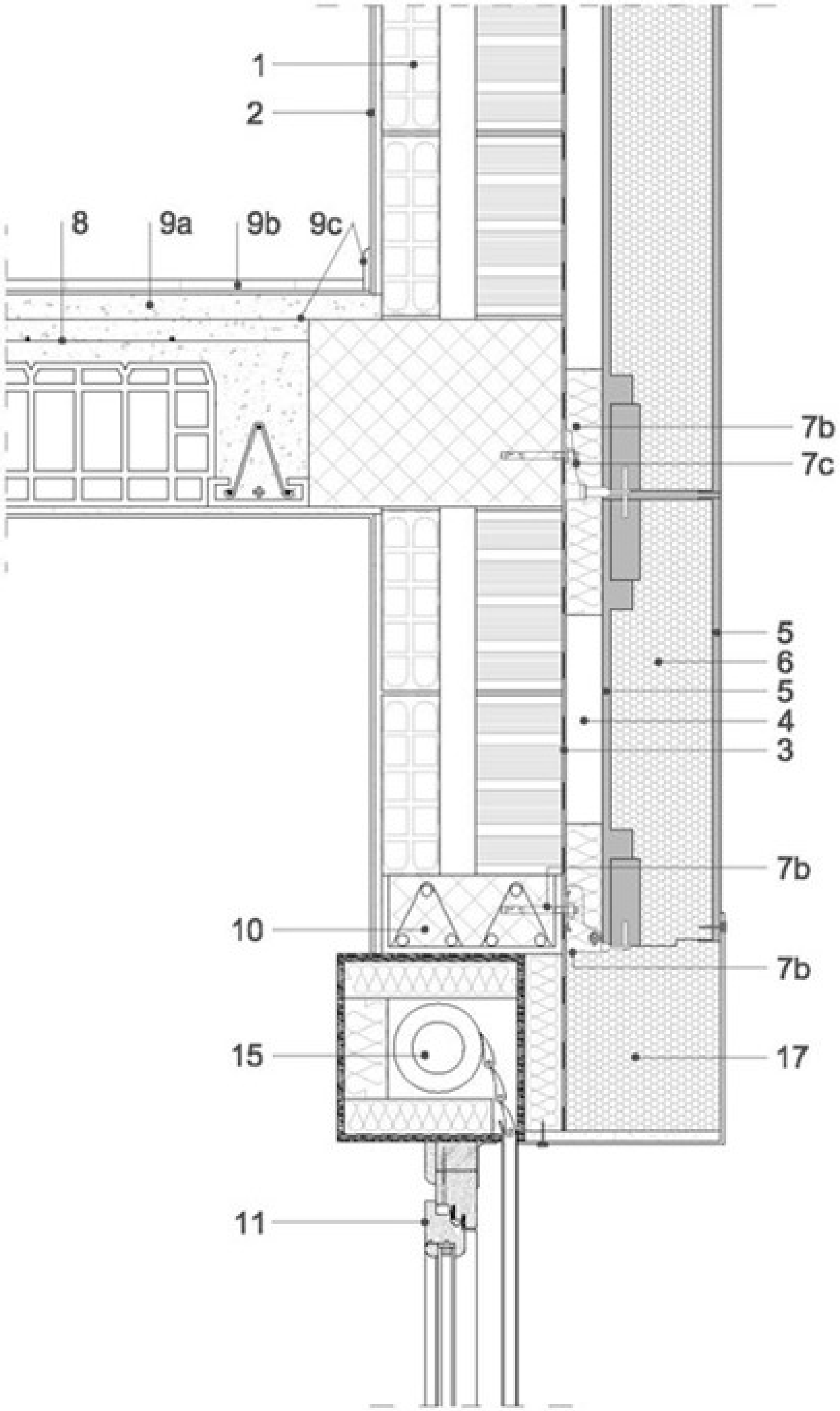


B.8



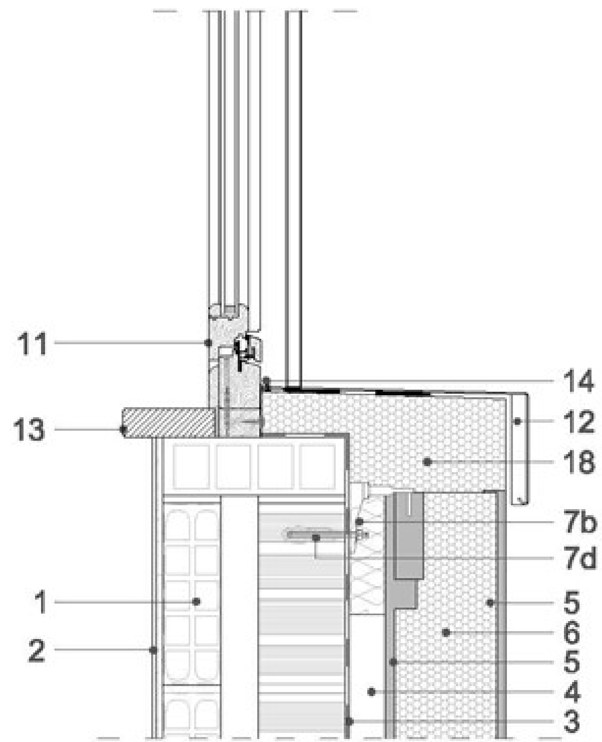
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1,25 cm, λ = 2.0 W/m^{2}K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 14.0 cm, λ = 0.037 W/m^{2}K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b);
8. Serramento in legno con vetrocamera;
9. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
10. Davanzale interno in pietra naturale, sp. 4 cm;
11. Chiusura in lamiera pressopiegata preverniciata sp. 1.5 mm.

B.9



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1,25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 12.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Tassello a battere in acciaio al carbonio zincato, ad alte prestazioni per carichi su calcestruzzo, Ø = 8.0 mm, lungh. = 105 mm (c);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo (sp. 3.5 cm), Pavimentazione (sp. 2.0 cm) e Finiture interne (zoccolino, materassino anti-calpestio, ecc.);
10. Architrave precompresso in laterocemento, dim. 25.0 x 12.0 cm;
11. Serramento in legno con vetrocamera;
12. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
13. Davanzale interno in pietra naturale, sp. 4 cm;
14. Sigillatura interfaccia cappotto - serramento;
15. Cassonetto in PVC coibentato + sistema di oscuramento con avvolgibile;
16. Chiusura in lamiera pressopiegata preverniciata sp. 1.5 mm;
17. Pannelli isolanti in polistirene espanso (EPS), sp. 19.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
18. Pannelli isolanti in polistirene espanso (EPS), sp. 13.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E.

B.10



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Barriera al vapore multistrato in PP.PE.Alu.PE.PP, μ = 66'667, sp. = 0.45 mm;
4. Intercapedine d'aria non ventilata, sp. 5.0 cm;
5. Textile Reinforced Concrete (TRC), sp. 1,25 cm, λ = 2.0 W/m^2K, d = 2311 Kg/m^3, calore specifico = 1000 J/kgK;
6. Pannelli isolanti in polistirene espanso (EPS), sp. 12.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
7. Sistema di supporto per ancoraggio dei pannelli in HPFRC, HALFEN DT Body (a) e BA Body (b) + Ancorante chimico ad alte prestazioni per fissaggi su muratura, Ø = 8.0 mm, lungh. = 105 mm (d);
8. Soletta latero-cementizia, sp. 30 cm;
9. Strato di sottofondo (sp. 3.5 cm), Pavimentazione (sp. 2.0 cm) e Finiture interne (zoccolino, materassino anti-calpestio, ecc.);
10. Architrave precompresso in laterocemento, dim. 25.0 x 12.0 cm;
11. Serramento in legno con vetrocamera;
12. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
13. Davanzale interno in pietra naturale, sp. 4 cm;
14. Sigillatura interfaccia cappotto - serramento;
15. Cassonetto in PVC coibentato + sistema di oscuramento con avvolgibile;
16. Chiusura in lamiera pressopiegata preverniciata sp. 1.5 mm;
17. Pannelli isolanti in polistirene espanso (EPS), sp. 19.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E;
18. Pannelli isolanti in polistirene espanso (EPS), sp. 13.0 cm, λ = 0.037 W/m^2K, d = 15 kg/m^3, calore specifico = 1450 J/kgK, classe di reazione al fuoco E.

ANNEX C

This annex reports, in more detail, the study carried out on the chosen solution:

TES Energy Façade.

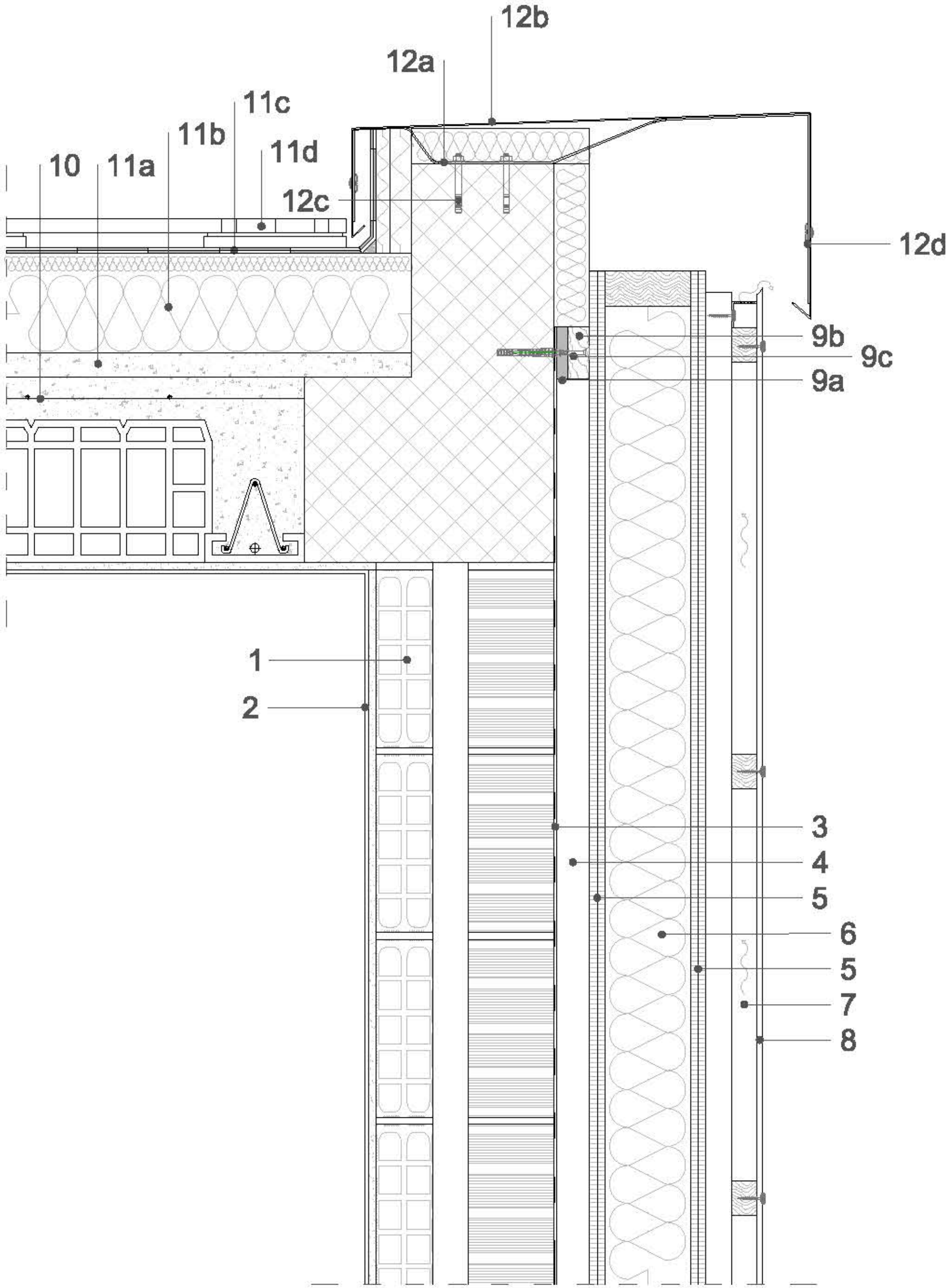
The nodes studied - and therefore developed - must not be understood as executive drawings of the solution itself but are examples of the peculiarities that this solution entails.

They are therefore suitable for understanding both the stratigraphy package, but also and above all the interfaces and this solution in specific points of the construction.

Specifically, the following were analyzed (scale 1:10):

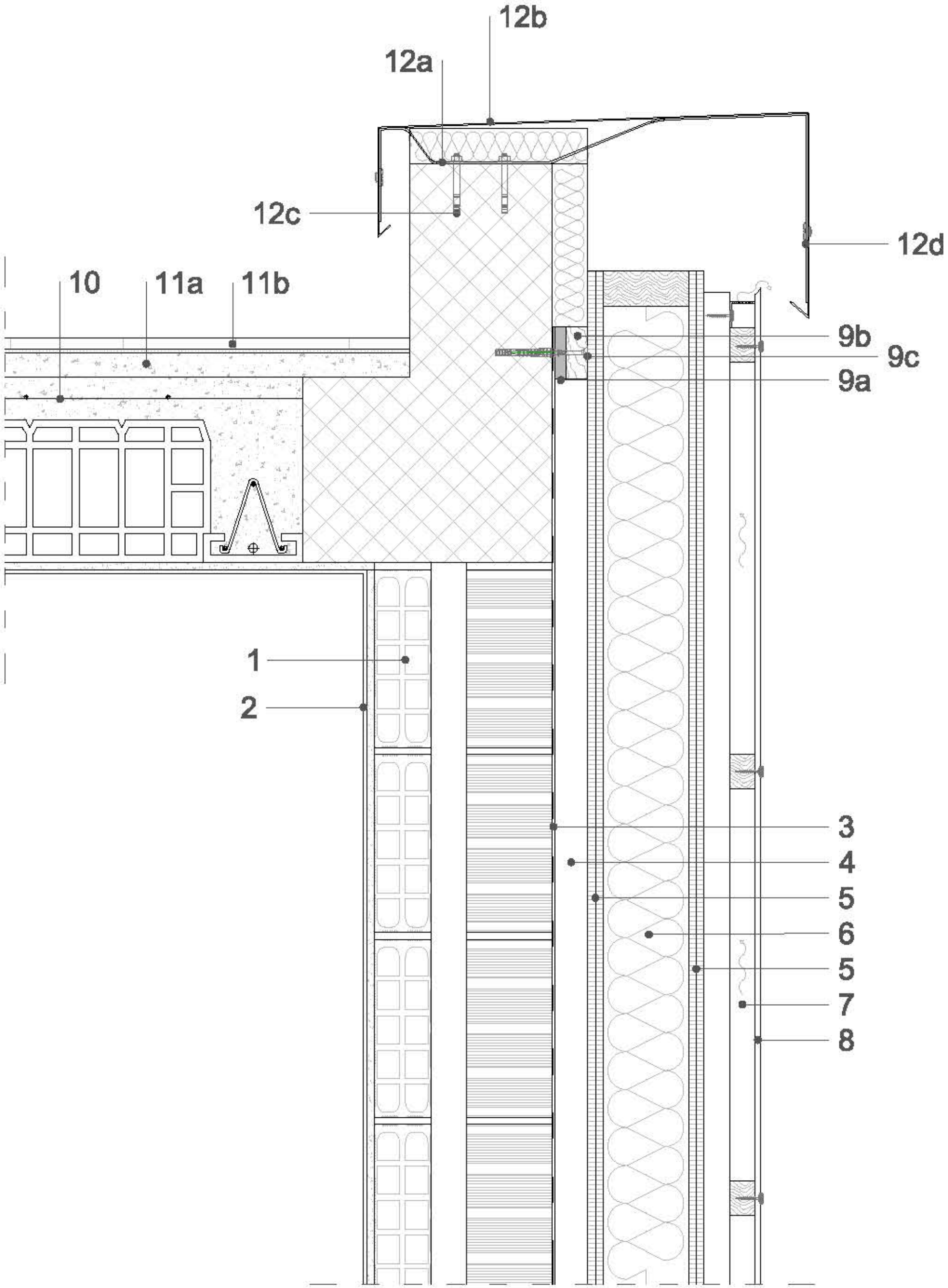
- **C.1** **vertical section: covering with roof refurbishment**;
- **C.2** **vertical section: covering with no roof refurbishment**;
- **C.3** **vertical section: inter-floor**;
- **C.4** **vertical section: basement**;
- **C.5** **horizontal section: panel-panel**;
- **C.6** **horizontal section: panel-panel corner**;
- **C.7** **vertical section: top window**;
- **C.8** **vertical section: bottom window**;
- **C.9** **horizontal section: side window**.

C.1



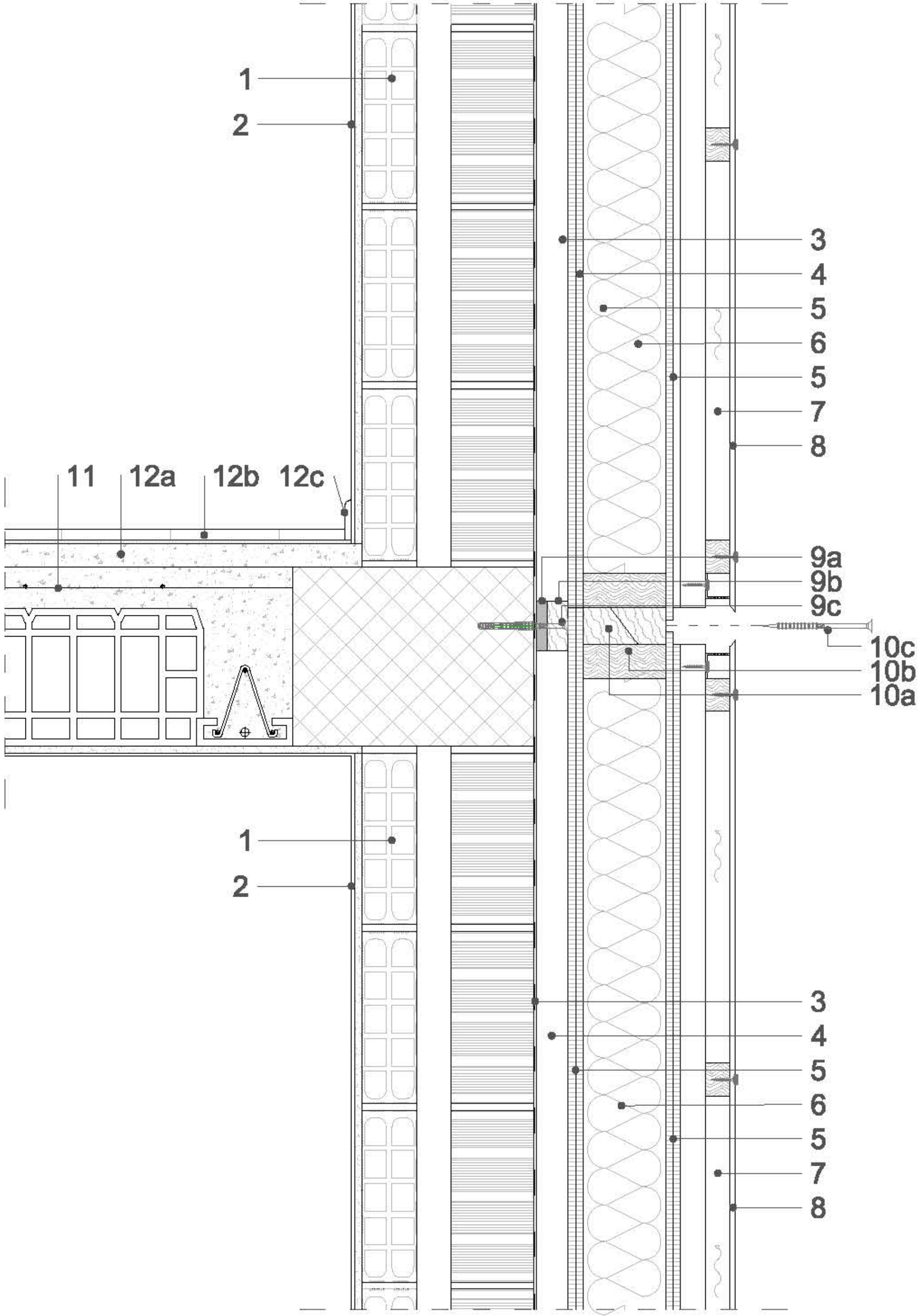
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
4. Intercapedine d'aria non ventilata, sp. = 5.0 cm;
5. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
6. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
7. Intercapedine d'aria fortemente ventilata (sp.tot. = 7.2 cm) + sottostruttura facciata ventilata in listelli di legno 36 x 48 mm;
8. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
9. Guarnizione isolante in EPDM (a) + Trave di accoppiamento in legno (coupling beam) (b); Tassello in plastica + Vite in acciaio al carbonio zincato con testa svasata, possibili applicazioni su calcestruzzo non fessurato, muratura forata, ecc., Ø = 10.0 mm, lungh. = 120 mm (c);
10. Soletta latero-cementizia, sp. 30 cm;
11. Strato di sottofondo, sp. 3.5 cm (a) + Pannello rigido in lana di roccia ad alta densità, calpestabile, sp. 12.0 cm, λ = 0.038 W/m^2K, d = 148 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0 (b) + Doppio strato di tenuta all'acqua in membrana bituminosa elastomerica armata in TNT poliestere e membrana bituminosa elastomerica antiradice in TNT poliestere (c) + Piedini in polipropilene per pavimento sopraelevato esterno e pannelli di calpestio (d);
12. Staffa di sostegno in alluminio sagomato ad U (a) + Scossalina di tenuta all'acqua, sp. 15/10 mm, pendenza del 1,5% (b). Fissaggio al supporto tramite tassello meccanico a espansione per calcestruzzo, Ø = 8 mm, lungh. = 85 mm (c); Rivetto a farfalla per il fissaggio della scossalina alla staffa di sostegno (d).

C.2



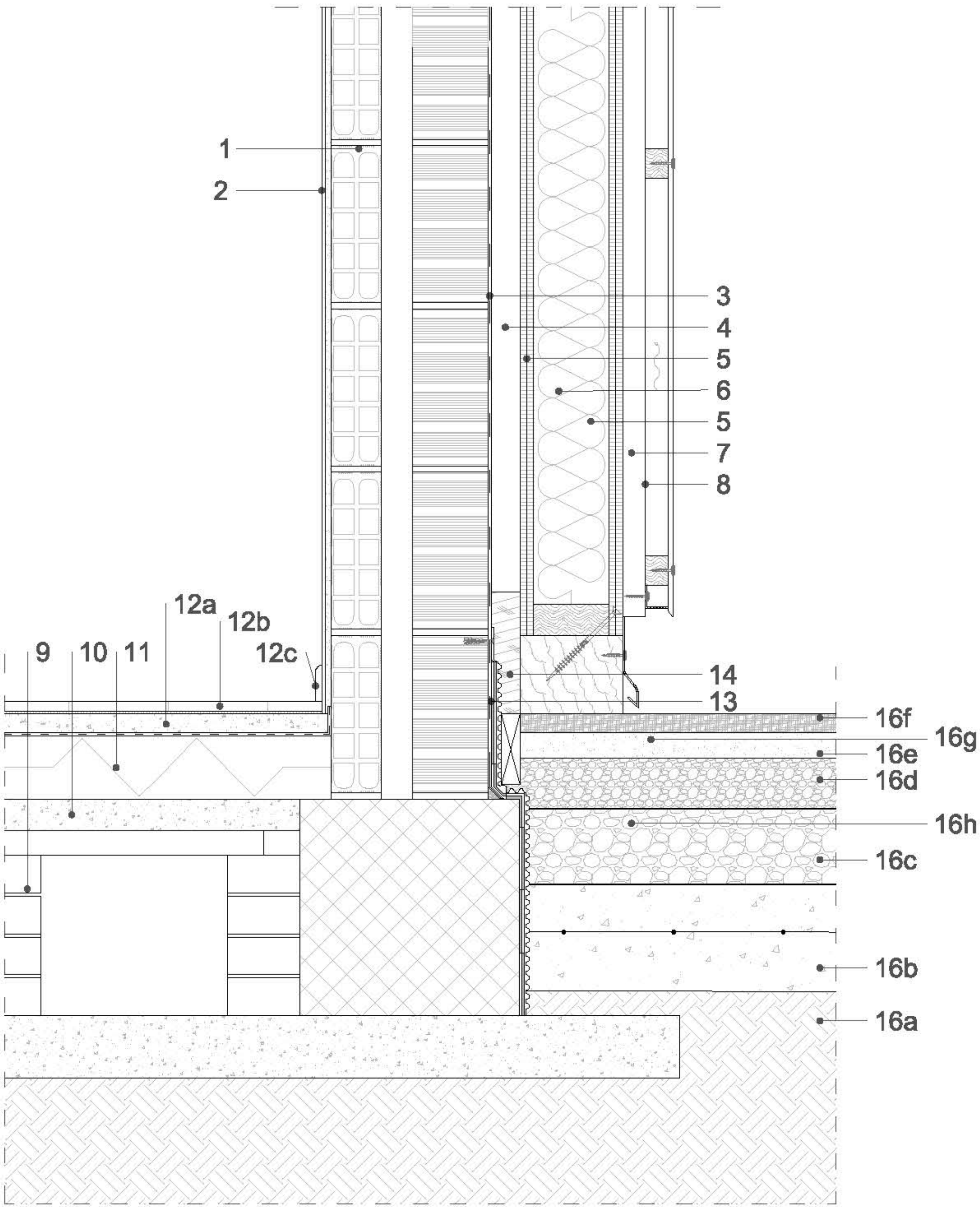
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
4. Intercapedine d'aria non ventilata, sp. = 5.0 cm;
5. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
6. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
7. Intercapedine d'aria fortemente ventilata (sp.tot. = 7.2 cm) + sottostruttura facciata ventilata in listelli di legno 36 x 48 mm;
8. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
9. Guarnizione isolante in EPDM (a) + Trave di accoppiamento in legno (coupling beam) (b); Tassello in plastica + Vite in acciaio al carbonio zincato con testa svasata, possibili applicazioni su calcestruzzo non fessurato, muratura forata, ecc., Ø = 10.0 mm, lungh. = 120 mm (c);
10. Soletta latero-cementizia, sp. 30 cm;
11. Strato di sottofondo, sp. 3.5 cm (a) + Piano di calpestio in piastrelle incollate al sottofondo, sp. 2,0 cm (b);
12. Staffa di sostegno in alluminio sagomato ad U (a) + Scossalina di tenuta all'acqua, sp. 15/10 mm, pendenza del 1,5% (b). Fissaggio al supporto tramite tassello meccanico a espansione per calcestruzzo, Ø = 8 mm, lungh. = 85 mm (c); Rivetto a farfalla per il fissaggio della scossalina alla staffa di sostegno (d).

C.3



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
4. Intercapedine d'aria non ventilata, sp. = 5.0 cm;
5. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
6. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
7. Intercapedine d'aria fortemente ventilata, sp.tot. = 7.2 cm + sottostruttura facciata ventilata in listelli di legno 36 x 48 mm (x2);
8. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
9. Guarnizione isolante in EPDM (a) + Trave di accoppiamento in legno (coupling beam) (b); Tassello in plastica + Vite in acciaio al carbonio zincato con testa svasata, possibili applicazioni su calcestruzzo non fessurato, muratura forata, ecc. (c), Ø = 10.0 mm, lungh. = 120 mm;
10. Giunto maschio-femmina di collegamento in materiale ligneo (a) + Traverso in legno di chiusura, dim 60x80 mm (b); Vite per collegamenti legno su legno in acciaio al carbonio zincato, dotato di testa piana svasata, Ø = 10.0 mm, lungh. = 110/160 mm (c);
11. Soletta latero-cementizia, sp. 30 cm;
12. Strato di sottofondo, sp. 3.5 cm (a) + Pavimentazione, sp. 2.0 cm (b) + Finiture interne (zoccolino, materassino anti-calpestio, ecc.) (c).

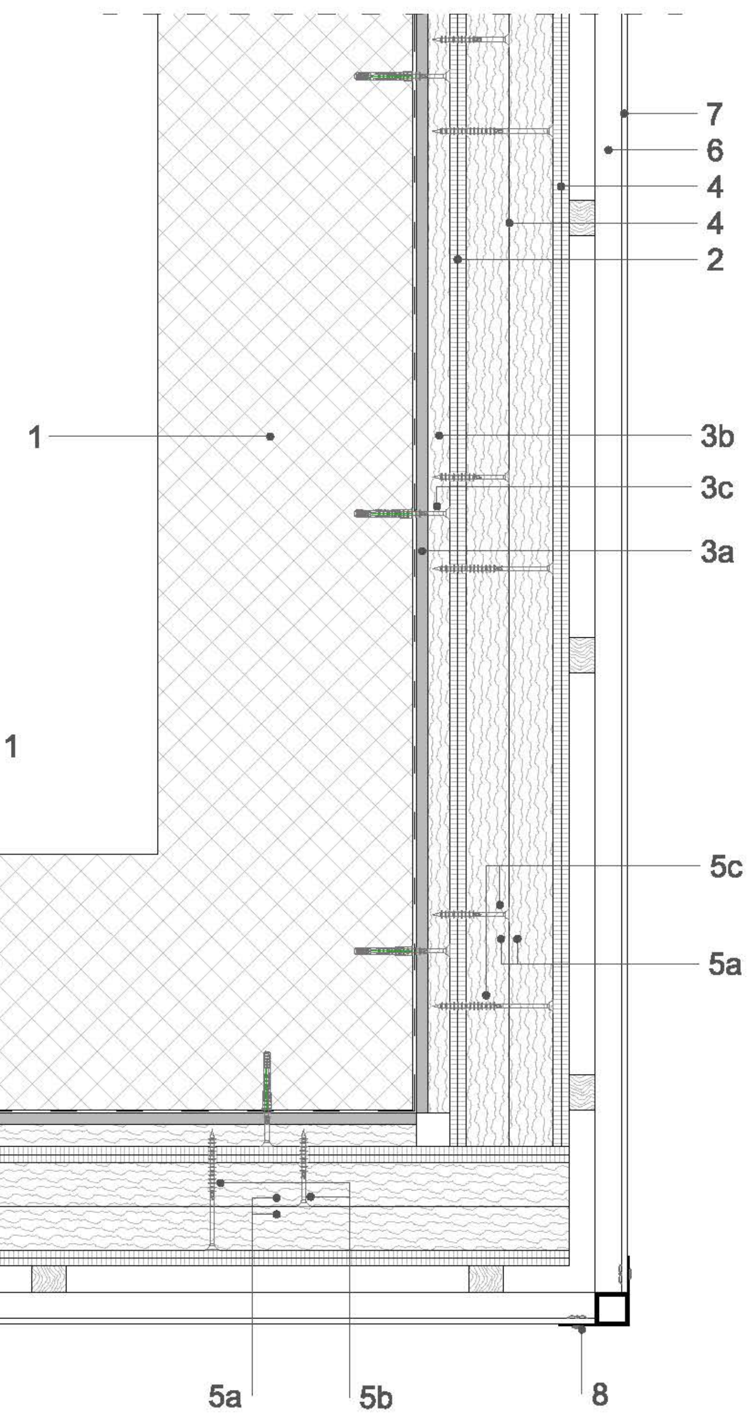
C.5



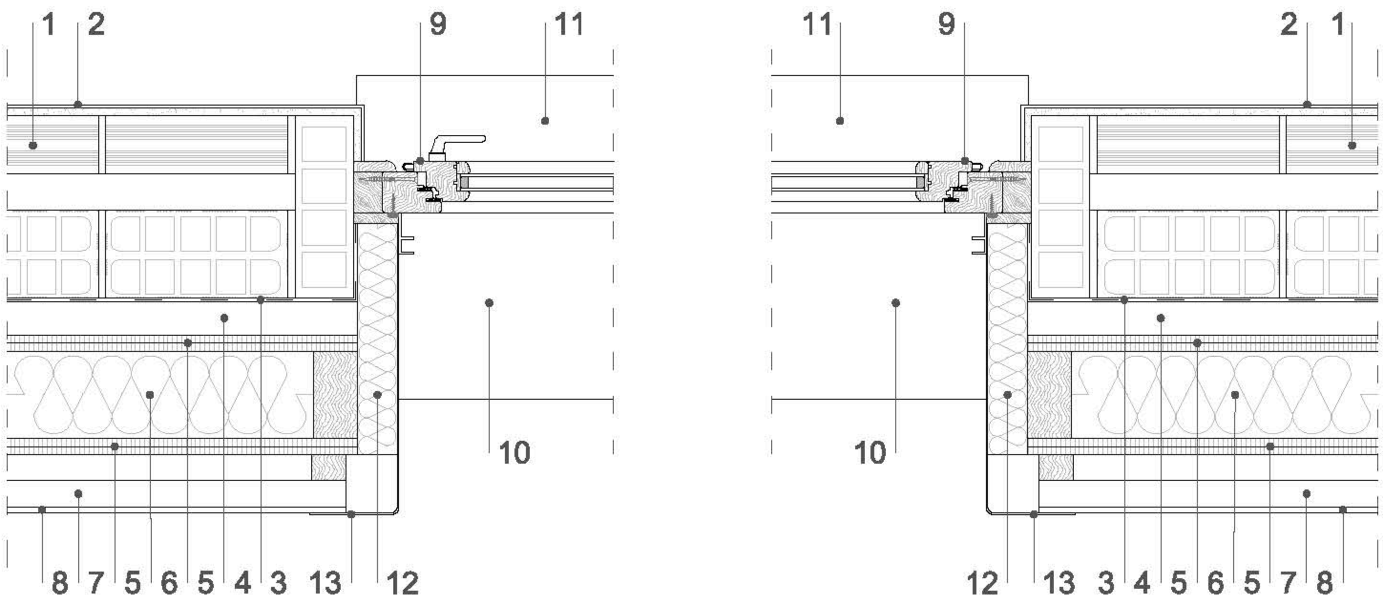
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
4. Intercapedine d'aria non ventilata, sp. = 5.0 cm;
5. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
6. Pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
7. Intercapedine d'aria fortemente ventilata, sp.tot. = 7.2 cm + sottostruttura facciata ventilata in listelli di legno 36 x 48 mm (x2);
8. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
9. Vespaio areato in tavelle di laterizio, sp. 4.0 cm, d = 350 kg/m^3;
10. Strato di posa e regolarizzazione del piano di posa / carichi applicati, realizzato in in calcestruzzo armato, sp. 5.0 cm;
11. Pannelli isolanti in polistirene espanso (EPS), sp. 10.0 cm, λ = 0.042 W/m^2K, d = 25 kg/m^3, calore specifico = 1400 J/kgK, classe di reazione al fuoco E;
12. Strato di sottofondo, sp. 3.5 cm (a), Pavimentazione, sp. 2.0 cm (b) + Zoccolino (c);
13. Sistema di impermeabilizzazione alla base dell'edificio, costituito da membrana bituminosa contro la risalita dell'umidità;
14. Isolamento termico e strato di protezione alla base dell'edificio, costituito da pannello in polistirene espanso estruso (XPS), sp. = 5 cm, λ = 0.035 W/m^2K, d = 32 kg/m^3, calore specifico = 1700 J/kgK, classe di reazione al fuoco E;
15. Elemento di raccordo e finitura zoccolo edificio;
16. Terreno naturale di riporto (a) + Cappa in calcestruzzo armato (b) + Sottofondo costituito da miscela di pietrisco e sabbia (c) + Strato di base in conglomerato bituminoso (d) + Strato di collegamento, o binder, in conglomerato bituminoso (e) + Strato di usura (f) + Cordonato in cls prefabbricato (g) + Membrana bugnata in polietilene ad alta densità (HDPE) (h).

C.6

1. Trave in calcestruzzo armato, sp. 35.0 cm;
2. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
3. Guarnizione isolante in EPDM (a) + Trave di accoppiamento in legno (coupling beam) (b); Tassello in plastica + Vite in acciaio al carbonio zincato con testa svasata, possibili applicazioni su calcestruzzo non fessurato, muratura forata, ecc. (c), Ø = 10.0 mm, lungh. = 120 mm;
4. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
5. Giunto maschio-femmina di collegamento in materiale ligneo (a) + Vite per collegamenti legno su legno in acciaio al carbonio zincato, dotato di testa piana svasata, Ø = 10.0 mm, lungh. = 110/160 mm (b);
6. Intercapedine d'aria fortemente ventilata, sp. = 7.2 cm + listelli orizzontali e verticali in legno, 48x36 mm (sp. tot. 72 mm);
7. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
8. Profilo verticale in materiale ligneo per rinforzo d'angolo.

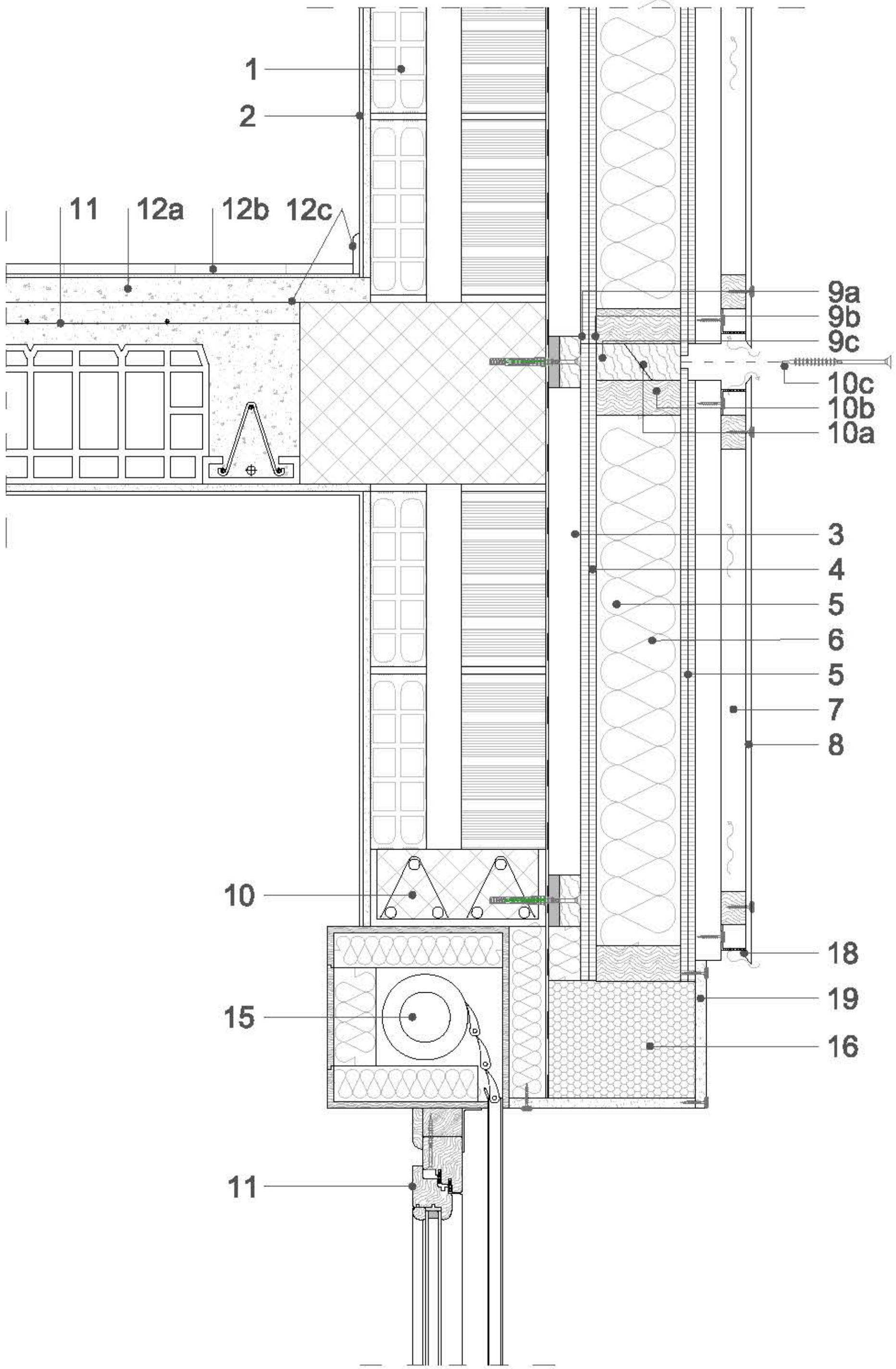


C.7



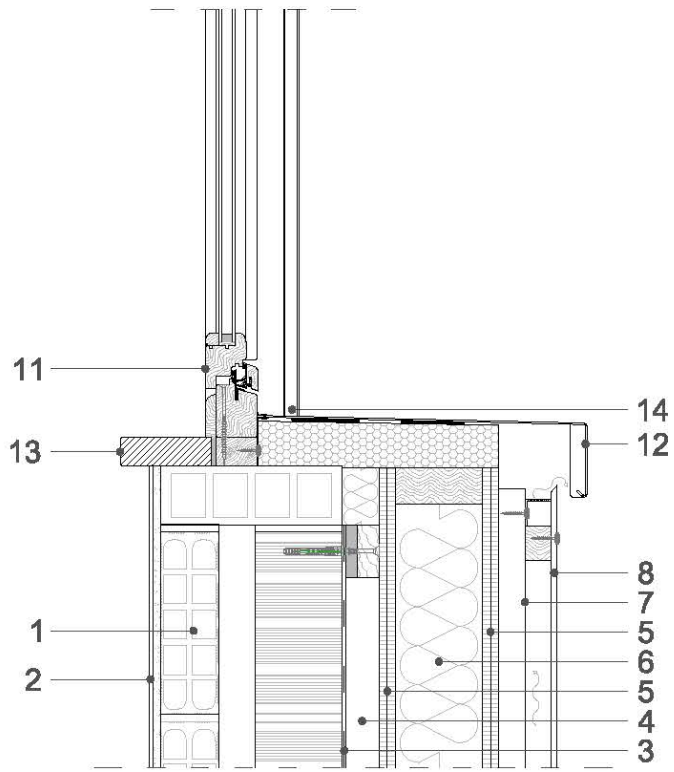
1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
4. Intercapedine d'aria non ventilata, sp. = 5.0 cm;
5. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
6. Sistema a telaio in legno + pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
7. Intercapedine d'aria fortemente ventilata, sp. = 7.2 cm;
8. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
9. Serramento in legno con vetrocamera;
10. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
11. Davanzale interno in pietra naturale, sp. 4 cm;
12. Pannelli isolanti in lana di roccia, sp. 5.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
13. Chiusura in lamiera pressopiegata preverniciata sp. 1.5 mm.

C.8



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
2. Intonaco di base + finitura lato interno, sp. complessivo 1.5 cm;
3. Freno al vapore multistrato in PP.PP.PP, μ = 66'667, sp. = 0.30 mm;
4. Intercapedine d'aria non ventilata, sp. = 5.0 cm;
5. Pannello in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3;
6. Sistema a telaio in legno + pannelli isolanti in lana di roccia, sp. 12.0 cm, λ = 0.04 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
7. Intercapedine d'aria fortemente ventilata, sp. = 7.2 cm;
8. Pannello di rivestimento in materiale ligneo, sp. = 0.8 cm;
9. Guarnizione isolante in EPDM (a) + Trave di accoppiamento in legno (coupling beam) (b); Tassello in plastica + Vite in acciaio al carbonio zincato con testa svasata, possibili applicazioni su calcestruzzo non fessurato, muratura forata, ecc. (c), Ø = 10.0 mm, lungh. = 120 mm;
10. Giunto maschio-femmina di collegamento in materiale ligneo (a) + Traverso in legno di chiusura, dim 60x80 mm (b); Vite per collegamenti legno su legno in acciaio al carbonio zincato, dotato di testa piana svasata, Ø = 10.0 mm, lungh. = 110/160 mm (c);
11. Serramento in legno con vetrocamera;
12. Davanzale esterno in lamiera di lega in alluminio sp. 10/10 mm;
13. Davanzale interno in pietra naturale, sp. 4 cm;
14. Sigillatura interfaccia con serramento;
15. Cassonetto in PVC coibentato + sistema di oscuramento con avvolgibile;
16. Pannello isolante in lana di roccia, sp. 20.0 cm, λ = 0.035 W/m^2K, d = 50 kg/m^3, calore specifico = 1030 J/kgK, classe di reazione al fuoco A1-s1-d0;
17. Chiusura in lamiera pressopiegata preverniciata sp. 1.5 mm;
18. Chisura in lamiera microforata sp. 1.5 mm;
19. Lastra in cemento fibrorinforzato, sp. 1.25 cm, classe di reazione al fuoco A1.

C.8



1. Parete di tamponamento in doppio paramento murario [blocchi forati 12.0 + 8.0 cm] e intercapedine d'aria, sp. 5.0 cm;
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10. Giunto maschio-femmina di collegamento in materiale ligneo (a) + Pannelli di chiusura in Oriented Strand Board (OSB/4), sp. = 22.0 mm, λ = 0.13 W/m^2K, d = 620 kg/m^3 (b); Vite per collegamenti legno su legno in acciaio al carbonio zincato, dotato di testa piana svasata, Ø = 10.0 mm, lungh. = 110/160 mm (c);
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17. Chiusura in lamiera pressopiegata preverniciata sp. 1.5 mm;
18. Chisura in lamiera microforata sp. 1.5 mm;
19. Lastra in cemento fibrorinforzato, sp. 1.25 cm, classe di reazione al fuoco A1.

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