Master in Construction Research,
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Energy efficiency in historic buildings: new materials for traditional envelopes

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Abstract

The energy consumed by historical buildings is much higher comparing to the modern constructions. The law is mostly related with the newly built constructions, stating requirements and guidelines for the energy demand. However, regulating the law concerning historical buildings is very difficult because of the need for preserving the historical and cultural value they represent. Moreover, recently discovered technologies can support the transformation process providing the most efficient solutions and increasing building's performance.

This dissertation will present research concerning a detailed state-of-the-art review on cutting-edge products and systems for energy retrofitting, in order to develop an inventory of suitable transformation/adaptation schemes and technological solutions for envelope components in a case study, by preliminary assessment of architectural, typological and constructional characteristics.

Keywords: Energy retrofitting, historical buildings, heritage preservation, cutting-edge products

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1. Introduction

The input of building and construction market into energy consumption has been an issue for years. Several solutions have been proposed, however the percentage of energy consumption in Europe has grown 92% in between 1971-2014 [1]. European committee has introduced directives (e.g. Directive 2012/27/EU and Directive 2010/31/EC), mentioning the need for the improvements in the construction industry. They try to initiate a regulation of the environmental aspect of construction, however the law concerns only newly build constructions and they are the smallest part of the building market. The real issue is already existing buildings, created with traditional materials and technologies that might not meet modern standards. It created a need for a universal system or an adaptable guideline on the procedures within that field. European committee's plan, to build only zero-energy buildings by 2030, does not solve a concern that are historical buildings [14]. Those buildings very often are in a poor condition because of lack of professional maintenance or they were abandoned for many reasons. The biggest challenge is the cultural heritage they represent, together with the limitations it causes. Studies showed that an impact on the environment is smaller during the renovation in comparison to demolition and replacement of the building with a new one [14]. The standard preceding cannot be applied because every case is unique, due to their social value, physical condition, regional restrictions, available technologies and funds. The approach must be adapted individually what extends the design period significantly, raising the cost and duration of the entire process. This dissertation will show that the process can be optimized by applying a similar proceeding on the buildings within one geo-cluster that would be defined by architectural, typological and constructional characteristics assessment. A geo-cluster can be named an area, district or a group of buildings with a similar characteristics, typology, location or techniques and materials used in the structures' construction. That need for the system is not only triggered by the poor energy performance but also a high energy usage cost of historical constructions. This dissertation will show some feasible alternative solutions using cutting-edge products and technologies that can be applied in areas with high historical heritage constraints. The implementation of smart-eco solutions into buildings with historical value will provide energy savings, reducing the environmental impact at the same time and eventually recovering the inherent bioclimatic behaviour. This type of a system would require a careful pre and post intervention assessment to collect all useful data for the future evaluation and possible improvements. This type of unification would lead to creating a method for particular geo-clusters that would not only shorten the design phase but also prevent making mistakes, which is the most problematic part of refurbishment. This type of a structured system used together with assessment tests would fill the gap in the construction industry within the topic of energy retrofitting of historical buildings. The promotion of this type of approach would also raise awareness among the industry, hopefully followed by lower emissions percentage and more efficient refurbishment process. Creating a method based on a geo-cluster idea would be based on a comparison of similar cases creating a pattern for a future proceeding. It could be defined through the most representative buildings or the most common construction style within a certain district.

The paper will show an analysis of related topics:

- A review of existing methodologies within the topic.
- The review of materials used most often for historical buildings refurbishment, renovation and maintenance.
- Standard solutions used for energy retrofitting and the advantages they bring. With a comparison to alternative options.
- The use of cutting-edge solutions that provide the most sustainable and efficient results and a merge between smart and environmental friendly use with respect to historical value of the building.

1. Aim of the research

The aim of this paper is to provide a review on available cutting-edge products and systems in order to outline some potential schemes and systems for energy retrofitting that could be applied as a standard proceeding on the envelope components in historical buildings, by analysis on a representative case study.

2. Delimitations

The study will not focus on technological solutions but rather on construction materials and systems. The reason for that is technological solutions allow to achieve satisfactory results without being invasive to the construction. Since this option is not always possible but also does not cause many problems, the author of this dissertation decided to focus on more challenging aspect of that issue, taking into account that the building envelope is both the performance interface between indoor and outdoor environments and the formal and material evidence of the historic-architectural identity

3. Methods and Techniques review

Comparing to the current building techniques, historical buildings are a very simple, heavy construction, based on the resources available regionally. Insulation was provided by increased wall thickness. Their low energy performance triggered the need for adaptation to modern standards but without affecting the inner climate balance by the intervention. That is why improving building’s envelope is the most challenging task for energy retrofitting.

Before any actions are taken the building must be tested and assessed for deep understanding of the actual problems. The most common struggles are as mentioned before high energy consumption but also poor daylight and limited opportunities for natural ventilation [14]. The assessment should define the areas that require the most focus. Very often buildings within the same geo-clusters struggle with the same issues. That kind of approach could set the rules for the buildings of the same type adapted to their own needs. In their paper A. Ahmed, M. Mateo-Garcia, D. McGough and M. Gaterell [2] measured the performance of some of the available technologies including experimental ones that could be a versatile solution in many cases of historical buildings refurbishment. They were tested in three separate locations as a part of the RESSEEPE project. [2] The special focus was put on the pre and post intervention monitoring to define the actual performance of every solution. Quoting Gupta and Banfield they show that it is equally important to understand the potential of every solution as well as the proper installation of every product. It is the key for achieving some actual results promised by a manufacturer. The approach they proposed is based on a database of solutions and digital simulations performed on the renovated building. They aimed '*to develop and demonstrate an easily replicable methodology for designing, constructing, and managing public buildings and district renovation projects to achieve a target of 50% energy reduction.*' They present a wide selection of modern solutions and some of them are still a novelty in a construction industry but perform on desired level, giving the results with either lower intervention damage or overall cost. The solutions proposed are also easily adaptable in different environment what corresponds with the aim of this study. The solutions chosen in the RESEEPEE projects will be presented in following chapters as a part of the construction materials review. Their results met the target of lowering the energy production by 50% what brings the idea of it being a successful system recommended to follow. The biggest issue that might occur is the limited choice of solutions that might either not meet the regional restrictions and regulations what is often the case in historical buildings renovation but also their availability at the market in that region. It lowers the adaptability of the system and makes it less unique to use in many different geo-clusters. The theory was tested in three different regions with different climates what shows that the system might be used but to achieve more flexible system this methodology should be modified and improved.

A. G. González, P. Bouillard, C. A. A. Román, S. Trachte, A. Evrard offer a solution that cooperates with a proposal of T. Konstantinou and U. Knaack [14] Their idea is based on creating a solution matrix based on buildings' typology. The system is very simple and it is supposed to guide the designer through a decision process instead of giving a ready solution. The user would choose a building's typology and be forwarded to the list of components and then to possible retrofitting options that are recommended for chosen criteria. All the proposed techniques would be taken from the previous interventions or the literature review. Moreover, it gives a wide scope for future updates and additions of solutions applied in particular cases what would minimize the repetition of the same actions in similar cases, for example within the same geo-clusters. This type of database could easily cooperate with the methodology presented in this dissertation.

This type of thinking leads to the considerations over technology used in data collecting. Using technology and innovative software is crucial in modern approach in construction business. The solution is either to use an already existing one and adapting it to the needs of a chosen methodology or creating a new software developed specifically to the proposed system. The solution proposed by M. Martinez-Hervas, J.J. Sendra and R. Suarez [16] is to use a Geographical Information System commonly known as GIS platform to gather and store information about constructional interventions. Because the platform is widely used and known the access to it would be easier but also data collection would be faster what would help introducing this methodology within the industry. Another advantage, provided by using this software is the geographical aspect of it. Following the idea of geo-clusters, this tool could help easily track and locate buildings searched by particular specification, either climate, typology, morphology, construction state, energy performance or location. This system could be easily evolved accordingly to market's needs because of its flexibility. Moreover, it can be used accordingly to designer's requirements. The idea is to not only introduce the final results but also the information gathered during the energy assessment before the intervention together with the results that the improvements provided. It has a potential of limiting the decision process from a very theoretical with the exact results achieved after the intervention to the situation where the final effect can be very accurate. Another advantage would be a characterization of the building stock in the regions collected in one, easily accessible database. In order to achieve the best energy savings in the region it would be recommended to perform the interventions in a unified and efficient way in the same area. This could lead to optimizing the long-term retrofitting strategies providing the most accurate information within the same database, created on a real-life cases and results.

Another point of view was presented by M. Tiberi, E. Carbonara. [5] Their analysis focuses on the economic approach, very often the priority of decision making in big projects, like historical buildings. They compared different combinations, analysing the potential savings, cost, payback period and the initial price with the actual environmental benefit. The dynamic simulations were performed using TRNSYS software based on building's thermal loads. The results showed that the most beneficial from the economic point of view would be a renovation without any envelope intervention. However, the comparison of cost and environmental gain showed that the best option would be a combination of complete envelope improvement combined with a thermostatic regulation system and photovoltaic array. The biggest issue with this method that it would have to be applied separately to every case since it is not flexible to be applied in restricted cases bonded by special regulations. Although the idea is important and should be used since the financial factor is often the most influential one and a proper analysis of all indicators gives different results and lead to diverse intervention choice.

A supporting remark was shown by A. Martínez-Molina, I. Tort-Ausina, S. Cho c, J.L. Vivancos in their review 'Energy efficiency and thermal comfort in historical buildings' [17]. They indicate the correlation between the Gross Domestic Product (GPD) and the work on the historical buildings retrofitting techniques development. They compared the situation on the stock market with the number of published articles in the same years. The research showed an interesting result that during the crisis period people tend to look for efficient solutions, spend more time on research and analyse the energy usage, while focusing on construction sector and development when the economic situation changes.

Another approach was proposed by F. Roberti, U. F. Oberegger, E. Lucchi and A. Troi. The interesting idea they introduce, is to design the intervention strategy based on quantitative parameters that can be evaluated in a hierarchy process. They performed a test simulation on a case study in Bolzano, Italy. [15] An old waaghaus was analysed with a purpose to change its function into a museum. The analysis was performed by several experts rating visual, physical and special aspects of the construction. Generic algorithm NSGA-II was applied on the results with a simulation performed on a popular software TRNSYS. A separate issue that had to be taken under consideration was the cultural value of the building filled with historical lime plaster, wall paintings and frescos. The proposed system is an interesting and a simple approach for the decision scheme. The potential development mentioned also by the authors would be to include cost and time of the constructional intervention into the approach in order to create more realistic proposals.

A very relevant work for this paper was written by M. De Fino, A. Scioti, E. Cantatore, F. Fatiguso [6]. It is important to understand the concept behind explained methodology. It was developed with an intention to have the possibility of applying it within a whole geo-cluster, that a specific view can be applied in a general one. Buildings can be divided into groups based on their environmental, architectural and constructional typology, what qualifies them within a geo-cluster. The aim is similar as in previously described papers to develop a methodology that can be used as a standard system and assessment tools for historical buildings and areas. This kind of a distinction limits the options of potential interventions within the area. It is based on three distinct stages analysis, diagnosis and intervention. This system offers several different actions that can be taken from the necessary step, from the whole geo-cluster analysis, building assessment in a context of heritage, through building recognition in terms of energy performance, pathologies and construction materials. That means that firstly there is performed an analysis of the general view, region, climate, style, construction and resources. Secondly, there is a diagnosis stage that focuses on the building itself. The fundamental areas of focus are the energy demand, structural assessment, the recognition of possible improvements needs and its heritage value. It is a process of recognition of the heritage properties within the researched area. The focus should be put not only on the type of the cultural heritage but also the proportion in the building, its function, value and the state of conservation. The last one is a design which recognizes the most suitable intervention options, available solutions, the integration of modern technologies and finally the possibilities for future development. This methodology provides also a tool to prioritise the

intervention options that can be replicated in similar cases. Together with the system there is provided an atlas of practical solutions for building components divided into categories:
- increase of thermal resistance
- increase of thermal inertia
- upgrade/ innovation of HVAC systems
- upgrade/ innovation of lightning systems
- integration of photovoltaic panels
- integration of wind power
- etc.

This type of approach can be used either for designing a refurbishment process or to prepare a long-term plan for the region development. The highlighted intervention type focuses on improvements of the building's envelope in order to increase the energy efficiency (Fig.1). The outer structure is relatively flexible and gives a lot of potential for improvements.

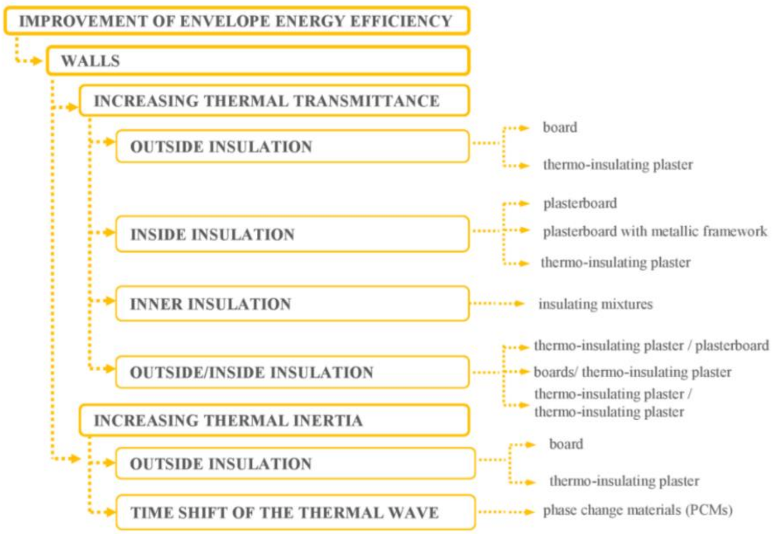

Figure 1 The decision process tree [6]

The figure above presents the design options scheme that is a tool providing choices for planning the improvements. It illustrates that there are many options to decide from in case there some limitations caused by an element presenting a historical or cultural value. The scheme is just a general frame, the actual decision must be based also on available resources, time, financial situation, architectural integration and the extension of possible intervention. However, this tool is designed as a help for the design process there should be also considered the structural safety and the maintenance of the chosen system. As shown before the benefits of every system must be considered in two categories: the instant results but also the long-term ones (for example cost, energy usage or produced emissions). The final stage that the whole approach leads to is a long-term strategy for future improvements within the whole area in terms of energy saving, ecologically friendly improvements, alternative energy grids, etc. The system aims to improve not only the single intervention case but to provide a scheme that can be applied to create a net of progresses also in a bigger scale.

A methodology approaching the topic from an alternative point of view was presented by C. Hermann, D. Rodwell in their paper that is a part of an ‘Energy Efficiency for EU Historic Urban Districts’ Sustainability’ EFFESUS program [7]. Their main concern is the balance in between historical heritage and retrofitting measures. The project has three goals that are closely related with this dissertation. Firstly, to prepare a selection of retrofitting solutions, both new and existing ones, developed or adapted for historical buildings. Second goal is a type of a methodology that were already listed above, that could be a selection tool supporting a decision-making process. The last is the educational function to spread awareness about the research outcomes and energy saving habits and behaviour. The decision-making tool proposed by the researchers is a software designed for professionals. It contains two databases, the one that provides all the data regarding the region, energy consumption, climate data and the heritage value. The second part is a compendium of retrofitting solutions and technical details. The results given by the software are the proposal of retrofitting options, however the user must keep in mind that every option must be carefully considered before application. It covers the issue that all the presented methodologies were missing, the tool does not cover all the fields included in the verification process, even though differently than previously presented solutions this software considers not only one or two aspects but *‘the software tool also assesses the impacts of each measure on indoor environment, fabric compatibility, heritage significance, embodied energy, and economy’*. Another aspect included into the software are impact assessment modules. With a help of that tool designers can estimate the consequences of the interventions. For example, potential energy savings or CO_2 emissions, payback periods or impact on the cultural heritage. The whole system is very detailed and complex that should make the proposed solutions relatively accurate.

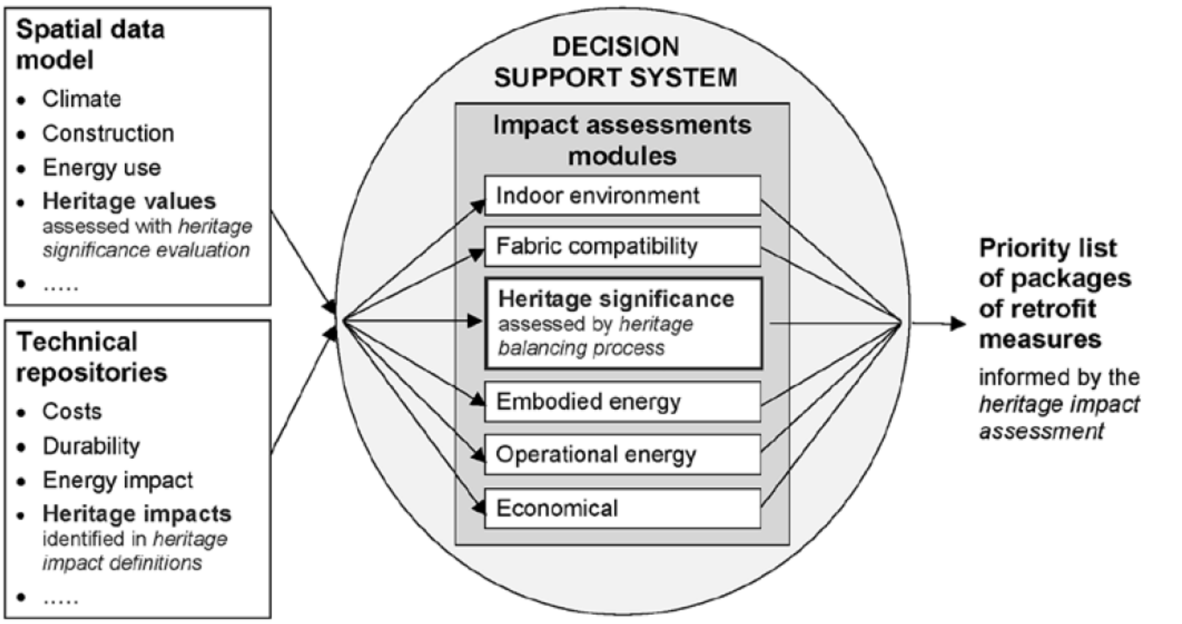

Figure 2 Decision support system scheme [15]

This wide selection of evaluation factors benefits with the most accurate results for the balanced proposal (Fig. 2). All the modules are developed and assessed during the EFFESUS program. However, the software designed as a part of the EFFESUS that is a European project, any users outside of Europe must adapt the tool to their own stock market and available resources.

All reviewed methodologies present different approaches to the same issue that is a unification of a decision-making process for the historical buildings renovation. They create the system based on different priorities that are all relevant to the problem. In general, they are based on a few main areas. The materials, like the comparison of the properties of materials on the market and then finding a hierarchy system for their application and suitability with the project. Another are focused on the cost and budgeting and efficiency as a main guideline for the decision-making and the final group targets buildings itself and not the external factors, trying to find a way that is the most unified to be applied for most of the historical constructions. However, the most general approach with a wide spectrum of application is the one presented the last and created as a part of a EFFESUS program. Such a big interest in the topic shows the need for clear rules and guidelines within the field of historical buildings that is not clearly restricted by law.

4. Selected materials review

This chapter focuses on the review of several cutting-edge materials available on the market that have a key impact on modern renovation techniques. They represent a group of innovative materials whose properties make them very suitable for the historical buildings renovation where the feasible options are often limited because the preservation of the cultural value is a priority in this type of projects. They differ from standard materials because they achieve much higher performance or lower intrusiveness. Some of them are particularly suitable because of their visual or mechanical properties like small thickness, light absorbance, etc. The following text describes in detail the main properties of presented materials and their advantages and disadvantages for a choice for a construction project.

- Aerogel (ASPEN)

Aerogel is a lightweight silica based product. It is a form of gel where the liquid component is replaced with gas what creates a product with 90% porosity. [18] Its properties ensure prevention of water leaks, wind drafts, shows superior thermal insulation characteristics comparing with standard insulation options, moreover it can be also used as a sound limiting material. It is used in different industries but mostly for thermal insulating, energy storing or carbon filtration purposes. Insulation itself is created out of silica oxide aerogel granulate with a mineral and cement free binder. The main advantages of this type of insulation is high performance, low weight and thickness, low thermal conductivity, flexibility and low vapour transmission resistance. It is often chosen as a solution during the renovation of historical buildings because it can be adjusted on site what gives the full flexibility in dimensioning, including situations with limited space or some very small gaps. It does not need a smooth surface and can be applied either manually or by the machine. The biggest disadvantages are the excessive cost of the material but also its harmful effect on construction workers applying the insulation, that is why it requires special safety equipment is necessary. The biggest advantage regarding historical buildings renovation that aerogel represents is its flexibility. Some buildings construction is very round or has difficult to insulate geometry. Because aerogel can be cut and bended to any shape it makes it a perfect solution for challenging or hard to access places. It gives a wide range of not invasive solutions in situations where they were not possible before. Moreover, because of its low thickness it can be applied on part of the surface that can be covered if situation occurs when a certain wall cannot be fully affected by the intervention. However, the elevated risk of intoxication for the workers makes it a dangerous material to work with. As mentioned before, additional steps must be taken to insure building's site safety. Workers handling the insulating process must be fully secured in a full body suits, googles, masks and gloves. The danger of aerogel's micro fibres accessing human system can be followed by a very serious health issues. Its harmfulness and a very high price make it a product that should be considered before being used in the project. However, the extraordinary properties that aerogel represents makes it a revolutionary product in the industry.

- Phase changing materials (thermal energy storage, cold energy battery, conditioning of building 'ice storage', heat waste recovery, off peak power utilization, heat pump system, solar power plants)

Phase change materials are an area of interest in scientific field for years. The first written studies are from 1979 [12] and were the group of materials for many researchers that focus their work on energy consumption within the construction industry. Because fossil energy is limited the alternatives that could reduce the consumption or supply energy from other sources became very desired technology in the industry. Development of phase changing materials could have a major effect on the behaviour of the building comparing to traditional solutions. Buildings built or renovated using the application of phase change materials show a behaviour typical for the passive houses. They work on the same principal as the thermal-mass without the heavy weight construction. It helps controlling internal temperature by shifting the time of temperature peaks controlling the cooling and heating cycle. They could be used both in renovation when adding extra load might be the critical decision or in new construction helping to achieve the best results regarding building's efficiency. Phase change materials are the alternative for heavy construction and design of thick walls. They give a

possibility to build a lightweight, airtight, well insulated construction with the benefits of the heavyweight one.
There are many types of combinations of the phase change behaviour with a different type of materials. The principal of this type of technology if that with the temperature change the material changes its condensation state. The most popular are: solid-liquid (fusion), liquid-solid (solidification) or liquid-gas (vaporization), gas-liquid (condensation), depending if the temperature raises or drops. Following that rule the material absorbs the energy, collects it and realises it when the temperature changes (Fig. 3). The most visible results can be observed during the summer when the temperature difference is the most noticeable. The effect of the absorption of the energy is the time shift of delivering it. For example, during the summer warmer temperature transfers inside of the building several hours after the temperature peak outside. This effect is called ‘passive like’ because it is a behaviour typical for the passive house technology. It can be applied in any climatic situation because the phase change temperature range is very wide. It starts from -10^{o}C to +80^{o}C.

The most important effect is called ‘supercooling’ and it was described by F. Kuznik, D. David, K. Johannes, J.-J. Roux [15] as a process of cooling of the liquid. It begins with a crystallization of minerals in the liquid creating a form in between solid and liquid state. This process is called nucleation. If the number of crystallized particles is too small it can remain liquid even if temperature decreases even lower. Then when the solidification begins the temperature of the material rises suddenly to the temperature of the phase change. The structure of the material depends on its type and future use. There are different organic and inorganic substances that can be used as a phase change material. Examples of organic ones presented by F. Kuznik, D. David, K. Johannes, J.-J. Roux [15] are: paraffins, fatty acids and the polyethylene glycol. The advantages that those substances bring is the fact that they are not dangerous and they have a good nucleation rate what is essential in relation to mentioned before ‘supercooling effect’. Moreover, they are chemically stable what means that they are safe and allows them to be used in a production of standard construction materials without it reacting with other components, the need of special technologies or problems with disposal. They are also available in large temperature range and high heat of fusion. However, because of their properties they show low thermal conductivity and low volumetric latent heat storage capacity. Depending on a component they can be also easily flammable causing the material to be less recommended because of the fire safety. The alternative are inorganic phase change substances that are salt hydrates. Comparing to the organic options they have a higher volumetric heat storage capacity but the high-volume change with a sharp phase change temperature. They are easily available what lowers the cost of the production. Another disadvantage for the production and construction use is that they are not a recyclable material and require segregation. They are not flammable what makes them a safer option from the fire safety point of view. On the other hand, they tend to ‘supercool’ what is not a desired property.

One of the most recent methods of phase change substances implementation into construction materials is microencapsulation. This method provides more flexibility for the ratio of phase changing substances into the future product. The principal of its behaviour is always the same. As the environment temperature changes, for example raises the heat gets delivered into the material and changes phase from solid to liquid and the opposite in case the temperature gets lower. The structure of capsules is simple. It is divided into small, separate drops of solid (for example powder), liquid or gas and it is coated with a polymeric material.

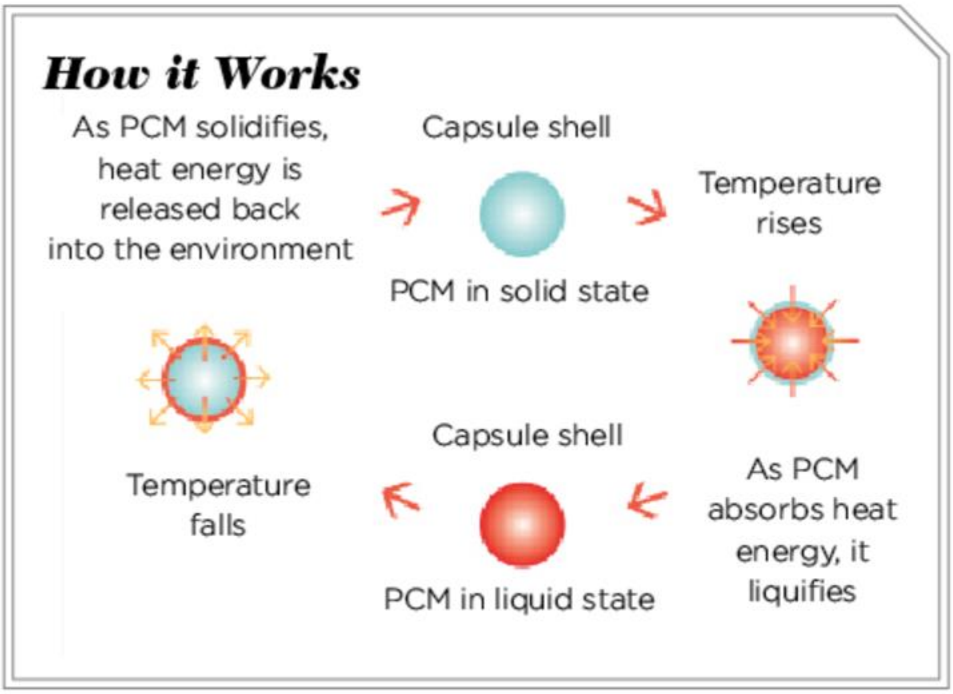

Figure 3 A visualisation of the technology behind Phase change materials [https://www.homebuilding.co.uk/phase-change-materials/]

There are several encapsulation techniques that depend on the future use of the product and desired properties. Methods can be divided into two categories, physical and chemical.
The most popular are [19]:
Physical: Pan coating, air suspension coating, centrifugal extrusion, vibration Nozzel, spray drying.
Chemical: Interfacial polymerization, in situ polymerization, matrix polymerization.
After the substance is encapsulated into small particles they are usually impregnated into gypsum, concrete or other porous material because their porous structure helps delivering the heat into the phase change material.
Thus, the substance inside the micro capsules changes phase the mechanical properties of the construction material stay intact, because all the processed happen on a micro level.

The most often products used with this technology are: roof tiles, gypsum boards, plaster, concrete mixtures, vermiculite, cement.

The typical examples are Energain panels, containing 60% of microcapsulated paraffin wax produced by Dupont [9]. The phase change temperature for this product is between +18^{o}C to 22^{o}C. Boards are 6mm thick and can be applied both for walls and ceilings below the plaster board and fixed in any standard way, either with nails, screws or staples that should be covered with an aluminium tape recommended by the producer.

Another example phase change material products called SmartBoard 23/26 produced by BASF [4]. Similar as Energain panels they can be used as boards but the company also produces ceiling times and aerated concrete blocks for more flexible usage. They are incorporated with 2-20 mm in diameter polymer capsules with a 15mm thickness of the panel. The number after the name of the product describes its phase change temperature that is essential while choosing the product accordingly to the climate zone of the building. These boards contain 30% of microcapsules that means about 3kg per 1m^2 of the board. According to the producer this ratio allows to keep all the mechanical properties of a standard board without increasing the fire risk.

The alternative shape of a phase change material is the one produced by Thermacool with their ceiling system. It is made out of a formaldehyde-free material that is 25mm thick. The panels are made out of capillary tube technology what means that the phase change substance is injected into a net of tubes.

For wall finishes a plaster with microcapsules of phase change material can be used. One of the companies producing this type of a product is Maxit-Clima. It contains 20% of the phase change substance. The properties of the product are very similar to the ones presented above for BASF's boards.

- Plaster/ Insulation paint (BEQUERIT)

The purpose of improving material's properties is to lower the energy waste. Because plaster is a natural technique used in many buildings the ability of using it as an insulating material brings many possibilities for energy retrofitting without significant changes to the building's envelope original appearance. Because it is a liquid material it can be applied in very thin layers resulting increasing thermal insulation without affecting the wall thickness. According to the substance's components and the binders, thermal plaster can be divided into three groups [3]:

- Based on cement and/or artificial binders
- Based on cement and expanded mineral aggregates
- Based on natural hydraulic lime NHL

All of them provide different properties and characteristics, but the main common behaviour presented by all types of thermal insulating plaster is the denser the mortar the higher performance material presents. One of the biggest advantages of this type of a solution is that it can be applied both inside and outside, providing a bigger scope of options for the intervention. It can be applied for different purposes in both residential and industrial buildings. Ceramic based plaster can be also used on small or hard to reach surfaces like balconies, joints, pipes or valves. It is very versatile and can be applies on many different surfaces. The recommended ones are: concrete, brick, ceramic blocks, silicates, stone, gypsum boards, polystyrene, XPS, metals, wood and wooden structures, PVC, plastic, acrylic glass and rubber. The reason for such a multiple use is the structure and the ingredients used for thermal plaster production. One of the types of this kind of plaster is made from latex/ acrylic base, synthetic rubber, micro ceramic balls, titanium oxide and a binder. The nanotechnology used in this product allows it to be used in extreme temperatures, what prevents the collection of moisture. It is an important feature especially for renovation of historical buildings which are more sensitive to water. It can be applied on surfaces from $+7^{o}C$ to $+150^{o}C$ and can resist temperatures from -60^{o} to $+260^{o}C$ after it dries down. As mentioned before the biggest advantages of this solution is a very thin layer of material comparing to the achieved results. Depending on the specific product, the energy demand and possibilities plaster can be applied in 1-12mm thick layers. Usually the product is sold white but the colour can be adapted accordingly. It should be applied as recommended by the producer however the main techniques are application with brushes, spatulas or mechanically under pressure.

- Multipor

Is a mineral insulation with European Technical Approval ETA-05/0093 [20]. It is manufactured as easy to adapt insulating boards. Because of its high density, 115 kg/m^3 [19] it is a highly insulating, light material that is recommended as a solution for external walls and roofs insulation. Because it is a silica based material with the porosity of 95% it allows flexible shapes without the use of unusual tools that can be used both inside and outside. A well-qualified construction worker can insulate the surface limiting thermal bridges or gaps to minimum, also during restoration. Multipor is a homogenous material what makes application very simple with a minimum risk for mistakes. Its homogeneity also ensures that the shape or the dimensions will not be affected by any pressure since it is a non-compressible material. The substances used during the production ensure that multiport is a completely recyclable material, recommended as an "environmentally compatible construction product" by the Institute for Construction and Environment (Institut Bauen und Umwelt e.V.) (IBU e.V.) EPD-XEL-2009212-D [20]. It increases building's safety because its formulation ensures protection and does not melt, create any toxic gasses or smoke in case of fire. Because of its high porosity insulating parameters are not affected by water since the material is water repelled, according to the manufacturer. This specific quality also allows the insulation from the inside without any risk of developing mould or the need for installation of the vapour barrier. The possibility of being safely installed on the inner side of the wall makes multiport

an excellent match for the historical buildings renovation. Very often the problem accrues when building's elevation presents cultural value. Then the only solution is mounting insulation from the inside.
The only difficulty that might occur is the preparation of the surface before the installation. Multipor boards require a completely smooth surface for the maximum performance, that in some cases might be impossible in a historical buildings case.

- Vacuum insulated panels (VIP)

Vacuum insulated panels are made from two elements, the core and the envelope.
The core is a highly porous material covered with air and moisture tight, heat sealed material. The middle part is usually made from micro porous powders, fibres or foams. It is necessary for the core to be highly permeable for all the air to be ejected creating vacuum. [3] Vacuum insulated panels must be miserable to infrared radiation so the radiative heat transfer is reduced. To achieve a low thermal conductivity the pressure must be low what can be obtained if the pores' diameter is very small. Also, the material itself must keep the initial internal pressure of 0.2-0.3 mbar and 1atm or 101kPa of the external one.

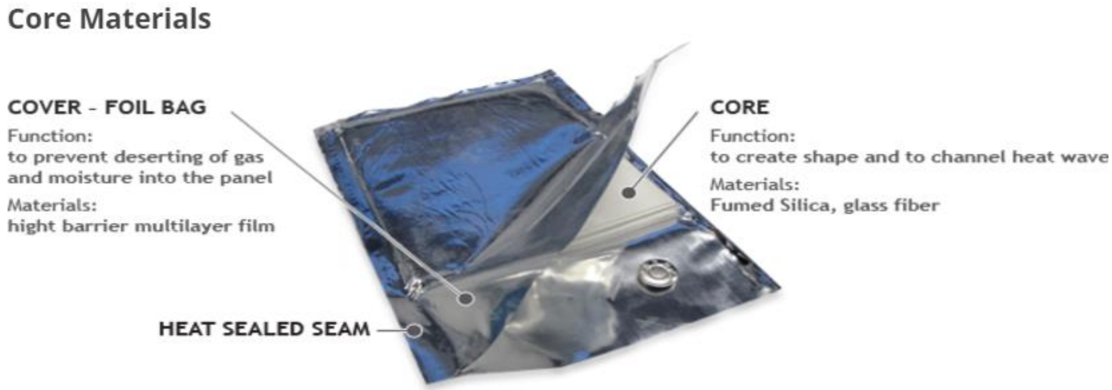

Figure 4 A visualisation of the Vacuum Insulated Panels structure [http://vipa-international.com/vacuum-insulation-panels]

The most used substances used in core production are: fumed silica, aerogel, polyurethane foam and glass fibre.
Fumed silica can be only used with added fibres for structural purposes. The pore size of this product is very small 20-100 nm with a density 200kg/m³. Standard fumed silica core characterizes with 0.003-0.006 W/(mK) under 20-100 mbar pressure. The biggest obstacle is that the material is not preventing thermal radiation what is one of the main properties desired in this product. However fumed silica is used in the construction industry for a reason that it is a non-toxic material that does not emit any harmful for the environment substances. It also keeps relatively low thermal resistance even in case the envelope gets damaged because fumed silica absorbs the water and moisture that might be captivated inside.
Another often used material are aerogels. Its pores are miniscule, only 20 nm in diameter with a wide range of mass density 3-350 km/ m³ at pressure 50 mbar. It is often produced with an

addition of carbon black to limit the radiative transfer. Its thermal conduction is usually 0.004 W/(mk).
The polyurethane foam was the first material used for vacuum insulated panels production. It shows the mechanical strength and porosity required to panels construction. However, comparing to the previous cases the pores of polyurethane foam are bigger what requires lower vacuum pressure to achieve thermal conductivity below 1 mbar. Nowadays it is not often chosen for the construction industry even if the production cost is lower compering to previous examples. The reason for it is its short life span effecting with a need for frequent maintenance and eventually replacement.
The use of glass fibre is similar as the use of the polyurethane foam. It is more often used for the production of containers and freezers than in construction because of its short life cycle. The reason for that is a low pressure that needs to be maintained to achieve the conductivity of 0.0015 W/(mk) because the pores of glass fibre are 1-12 µm.

The opposite requirements comparing with the core are applied for the envelope. It must be gas and water impermeable to prevent the material from being damaged with the weather and climate condition and to extend its lifetime. Any perforation or damages of the envelope will affect the efficiency of the product but also the external factors like temperature changes and humidity rate will affect the performance of the panels. The low conductivity is essential for limiting the issue with thermal bridges typical along the panel's edges. That is why the material for envelope's production must be carefully chosen accordingly to the future purpose of the product. Moreover, increasing panels' size will lower the possibility of thermal bridges and potential losses because less panels will be used to cover the same area. The most used materials for the panels' envelope are: metal laminate and metalized multi-layered polymer laminate. It must be very tight and well-sealed to prevent lowering the properties of the material while aging. The envelope is made out of three different layers: the sealing layer, the barrier layer and the protective layer. The metal laminate is usually made of aluminium laminate of a 5-10 µm thickness that is laminated in between two layers. An outer one that is a protecting layer produced from polyethylene terephthalate commonly known as 'PET', and the inner, sealing layer shaped from polyethylene. All those layers create aluminium laminate, generally called aluminium foil. Aluminium's thermal conductivity is 210 W/ (mK) and polymers's layers 0.25-0.30 W/(mK). It must be taken under consideration during the vacuum insulated panel production together with core's thermal conductivity value to result the value for the whole panel.
The second solution includes metalized multilayer polymer laminate. It consists maximum three layers of metal coated polyethylene terephthalate (PET) and one inner layer of polyethylene that seals it together. The coating is made of aluminium of a thickness 20-100 nm. The solution is often adapted for the production of vacuum insulated panels because increasing the number of layers prevents damages and perforations of the product while included polymers limit thermal bridges. However, this type of combination increases the risk of moisture and air permeability that is caused by lower thickness of the material.

A typical vacuum insulated panel is about 5-10 times more effective than standard insulation solution [10], with 8-10 times lower thermal conductivity. They characterise with a stable long-thermal performance around 0.004 W/(mK) – 0.008 W/(mK) even after 25 years of usage. Standard insulation will always have a thermal conductivity higher than the air one (0.026 W/(mK) that is why this technology where the air is 'vacuumed' from the product achieves more satisfying results without increasing the thickness (Fig. 4).

That is why a proper installation is essential for achieving the best possible performance results. Moreover, careful planning and panel placement design shall be conducted to eliminate the necessity to adjust, cut or modify panels in any way, since the technology is only effective in its original manufactured shape. Any on-site modifications to the panels will pierce the vacuum and invalidate the panel performance, lifetime and durability.

It is often chosen over alternative solutions because of its low thickness that gives new options for design and construction solutions. It is mostly used when the space for the intervention is limited, internal room area is small or important for the building or when the wall thickness cannot be modified.

- Electrochromic windows/ Low e coating /sage glass (ISO EN 6946)/ Pane replacement (double glazing)/ Window frame (3encult)

Low e-coating is a technology that prevents ultraviolet and infrared waves exposure inside of the building. It reflects the long-waves without limiting accessibility of visible light inside of the room. E-coating is a transparent coat applied on one of the window's glass layers. Its main property is reflecting the heat waves, what gives the effect of keeping the warmth inside during winter and reflecting heat energy from the outside during summer. There are two types of coating: passive low e-coating and solar control e-coating. The first one focuses on the heat control inside of the home creating this way 'passive heating' without an external supply. The second option limits solar gain preventing overheating reducing the energy consumption of air conditioning and keeps the building colder. The main techniques of production are 'hard coating' and 'soft coating'. Hard coating is done by applying pyrolytic coat while the glass is being produced. It melts into a hot surface of the glass becoming one material. The soft coat is magnetron sputter vacuum dispositioned. The location of the coating is essential for the results that are desired. The first option is to place the coating on the glass facing outside, the second one is to apply two layers facing each other for extra insulation. The last one is to apply it facing indoors for the 'passive' effect.

- Expanded cork

Expanded cork is available on the market in two forms, as an insulating slab and expanded cork granulates. This type of insulation is 100% natural, recyclable and renewable. Can serve several insulating purposes as thermal, acoustic or anti-vibration insulation. The granulate is a coproduct from expanded cork slab production. The most common purposes for the expanded cork granulate are insulation of pitched roofs, filling gaps that are difficult to reach for example joints, using it as an replacement for wall's cavity or a filling for lightweight concrete screed. Using the waste of a prime material generates low amount of waste because it is being reused to other purposes. The production of cork insulation is described by M. Demertzi, J. Sierra-Perez, J. A. Paulo, L. Arroja, A. C. Dias [8] in their paper related to produced in Portugal by Amorim Isolamentos S.A, expanded cork life cycle analysis. The cork is collected in its raw form and dried for minimum six months. After that period, it is being moved to a trituration machine and shred into small particles. At this stage, a high-quality material is separated from cork dust, small stones or sand. The dust is burned and used for thermal energy production used in the following steps. Sand and stones are transported for agricultural valorisation. The usable material is heated up to 350-370^{o}C for 20 minutes and shaped into blocks. During that process cork expands 30% and this is why the product itself is called 'expanded cork slab'. After that procedure, the process of cooling begins. Metallic perforate needles are inserted in the middle of every slab and injected with water to lower the temperature. The water is not being wasted but it circulates during the complete process. The next stage is complete cooling and stabilisation of blocks that lasts approximately one week. Afterwards it is being moved to rectification machine and automatically adjusted to desired dimensions with chainsaw. The dust created during that process is being vacuumed and burned for thermal energy. The slabs must pass a visual inspection and be approved for export. The lower quality product is granulated in another trituration machine together with small pieces that are left after adjusting slabs into required dimensions. In that process, a coproduct (expanded cork granulates) is being created and prepared for future usage. The granulate is packed into raffia bags and stored before further transportation. Because of low energy needs for the production and no other addition to cork mixture like aggregates or additional chemicals. The product is changes properties and adapts to the need only using natural methods like elevated temperature, cooling with water or using time to achieve certain stage. It is environmentally friendly and as proven before renewable product. Certain production aspects can be questionable. Like the use of trees for insulation production or the life span of a product this kind. Overall it is a lightweight product with a high thermal resistance not harmful for the environment, does not affect other construction materials, it is easy to produce and often available locally or easy to import. That is why its popularity grows as a choice for historical buildings renovation.

6. Decision making

Protecting cultural heritage is an important and responsible task. Trying to lower the consumption usage in this construction sector should be done carefully and well thought through. Many methodologies described in previous chapters show different approaches that ensure choosing the best reconstruction option taking all factors under consideration.

However, protecting the cultural value of the building should be a priority in every case. Sometimes the necessary interventions will not be possible because it would conflict with protecting the building. That is why a proper assessment and validation system should be applied while designing the changes.

Suitable solutions should be chosen based of few criteria:

- The compatibility with the original materials and components especially when the materials originally chosen for the construction represent a historical value.
- Architectural integration.
- Life cycle
- Technical reliability
- Environmental impact
- The evaluation of the extent of the intervention and energy used compared to the possible, estimated energy savings.
- Cost
- Safety of application and usage
- The climate of project's location should have an impact on material's choice, suitable for its location considering product's efficiency.
- Cost
- Functionality
- Availability

There are three stages of the process for building's energy retrofitting; analysis, diagnosis and intervention. The analysis starts from the urban scale and ends on the components. IT investigates the historic town focusing on environmental, architectural and constructional aspects. The diagnosis stage is based on previously collected data, assessing buildings typology, performance based models and parameters. It focuses on estimating the balance between the necessary improvements and the preservation of the cultural value. The definition of suitable strategies for each component leads to intervention stage transforming the proposed strategies into technical solutions, creating a guideline for an 'descriptive models'. The proposal can be transformed and applied on an actual case followed by a plan for the improvements within the whole geo-cluster.

First step, when approaching such a process, should be a thorough data collection. Starting from the all possible about the area the building is located. There are two types of data: the one based and already collected locally and another collected on site based on direct tests and samples. Contacting municipality, weather stations, local archives and receiving geo-data and maps would be an example of the first type. The second one would include inspection on site, running several tests both inside and outside of the building and long-term monitoring of building's behavior for external factors. The test would evaluate the materials used, envelope's construction, decay patterns, soil content, sun operation, etc. A special attention should be put on researching the historical value of the renovated project. The historical and urban evolution of the whole district and its relation to the building itself, the areas that need to be protected and also take under consideration in which way the building site should be arranged. Data collection and the analysis should be based in a geo-cluster scale. It provides all the standard and representative data for the particular district.

Data collection from available sources	**Direct survey**
• Archivist and bibliographic records • Climate data and weather standard behavior • Geo-references • District's data collection • Historical evaluation • Urban development • Morphology • Architecture	• Software simulations based on data • Climate parameters • Observation of functional and typological characteristics • Observation of typical materials and techniques used • Decay patterns

Table 1 Table showing the activities related with the assessment [11]

All the mentioned in a table (Tab. 1) activities, allow collecting data regarding: geometry, dimensions, orientation, functions, occupation profiles, surface finishing, transparency ratio to the opaque surfaces, building's components and the state of conservation/maintenance. [6]

After the data is collected the evaluation of building components should be performed. The assessment should be based on building's original and future function, materials used, areas and components that need protection or special treatment, state of conservation and damages that need to be renovated. Should specify the historical and architectural values, bioclimatic qualities, decay patterns and failures, assessment of energy deficits. Moreover, the energetical behavior of the building should be investigated in order to find the most suitable solutions. The observations should be related to humidity content, ventilation, energy consumption and the extend of possible interventions in that field. The energy analysis should concern data like thermal inertia, air and moisture permeability and thermal bridges. This kind of information can help designing necessary intervention steps and prioritizing focus points for the project. Once an analysis is performed it should be followed by assessing other buildings within the same district. If a significant amount of buildings fulfils the same criteria (Tab. 1). Some of the building types can be identified and be implemented in the listed phases. This process could include the whole identified geo-cluster is the analysis and interventions are validated on few building types.

Software analysis can be a very useful for the energy and what follows next priorities assessment. Previously done simulations can help prioritize the hierarchy of necessary changes and show which combinations are the most efficient. The maintenance or following construction works should be limited to minimum that is why durability of materials and their life span can be a crucial factor influencing a decision, even over the price of more durable material. However, renovation of historic buildings is a very specific type of a constructional project since the value of the cultural heritage is a priority. The focus should be on preserving as much of the original structure as possible, improving the energy performance at the same time. The most common and effective approach is to improve building's envelope increasing the efficiency of the building.

The following stage focuses on building's compatibility with potential solutions. It concerns materials suitability with the original structure, visual and architectural results, functional needs, material's life expectancy and the final cost of proposed solutions.

The last stage should relate back to the whole geo-cluster, planning potential transformations within the whole district, based on already proposed solution for the representative case. All above mentioned stages are represented in the scheme below (Fig. 5).

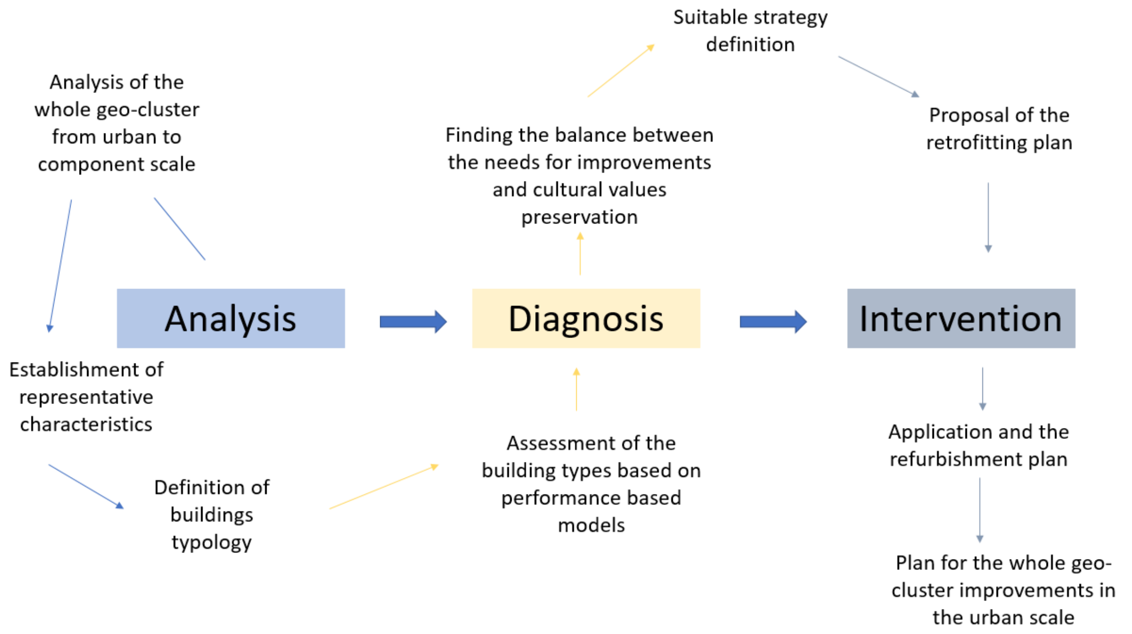

Figure 5 Scheme of above mentioned stages

7. Molfetta Case study

Molfetta is an old town located 40km north from Bari. The climate is typical for this region, hot and dry during the summer and very humid and rainy during the winter, with a lower temperature.

The town is situated in the east of the southern region of Italy, Apulia. The full analysis was based firstly on a whole geo-cluster assessing morphology, typology and original materials and application techniques used in the construction. [12] It must be mentioned that an old town of Molfetta is a well-preserved structure kept in an original arrangement. It was developed under Byzantine influence and then by Lombard's and Norman's but the main part is dated for middle-age period with certain improvements over the years. The old town is

ellipse shaped, surrounded by a densely built port and solid stone buildings creating a barrier against attacks. Narrow and compact streets did not only ensure safety but also limit sun and wind exposure.
Also, the fact that buildings are built next to another change their behaviour significantly. For instance, a 'tower house' has only two external walls because the other two are shared with an aligned, neighbour building. This characteristic influences the energy performance of the building and the number of factors affecting it that are necessary for the analysis. This case is a standard representative of an Italian residential building and is a good example of possible improvements that can be applied. Most of the buildings were maintained, however, mostly windows were replaced but most of the other components kept in the original stage. The construction of Molfetta's structures is based on natural and locally available materials, like stone or wood. Buildings can be divided into two types: 'tower house' and 'palace house'. This case study represents the first type, 'tower house'. The difference between these two is the apartments' location. The 'tower' type is more vertical where the dwellings are placed on several floors, occupying one narrow building. Usually small shops or services are located in the bottom floors and the residential apartments in the top ones. The 'palace' style is a horizontal one. The rooms are placed on one floor but along several, usually two or three buildings. Both types can be distinguished from the outside, by an observation of windows placement.
As mentioned before the case study is a typical 'tower house' made of traditional materials and built in a traditional to that period style. It is a four-storey building with a shop in the ground floor and a residential area in the upper floors. The general dimensions of the building are 4x8 m for each floor. The analysed case is a representative building type from that area presenting the most typical construction and building methods. The case study analyses the general representative structure and not a specific building. The example shows the typology, building solutions, materials used and architectural characteristics typical for this geo-cluster based on the analysis of the whole area.

7.1 Description of the construction

The whole structure of the house is based on a ground floor slab, made of concrete. It is placed on stone blocks for support and an equal load transmittance and a layer of gravel to prevent moisture penetration.

The wall construction of the house is made of two layers of stone blocks with an inner cavity filled with a mortar mixtures and natural aggregates. The wall is relatively thick, 65-100 cm what is very beneficial for the heat transfer, keeping the building cooler during the hot days and warmer during the cool ones. As a difference to the other floors, the ground floor is un-plastered what limits the options of interventions in that area because the original look must be maintained so any additional layer cannot be applied. The wall is plastered with a 3mm thick layer from the first floor and up (Fig. 6), while the ground floor is left un-plastered, exposing the natural stone. It must be mentioned that only two out of four walls must be considered changeable. The two 'side' walls are shared with the buildings on the side and are not affecting the results of the energy calculation. Only the front façade and the back wall are influenced by the outside conditions and are exposed to environmental conditions.

Figure 7 An example of Molfetta's typical external wall finishes [12]

Figure 6 Example of a window in Molfetta [12]

The windows are very narrow usually and as mentioned before they were replaced from the original ones. They are double glazed windows with wooden frames. However, it must be taken under consideration that the frames must be preserved wooden and the replacement must be restricted to the actual thickness of the frame to fit in the window opening (Fig. 7).

Figure 8 An example of Molfetta's typical ceiling/roof structure [12]

The roof construction is very light-weight and does not prevent heat transfers because of its thickness and lack of insulation. It is made of wooden construction finished on the outside either with a stone or a waterproof membrane. This type of construction has a lot of potential for construction and energy performance improvements. Comparing with the other components the roof structure is very thin, only 18 cm. It is built from wooden beams and slabs finished with a sloping lightweight concrete and original stone tiles (Fig. 8). The tiles are typical floor tiles but because the roof construction is flat they have been used in this structure. Because they are original they shall be preserved because of their heritage value and the atmosphere of the building.

The construction is very solid and well preserved (Fig.9). However, the energy performance of the building can be improved in order to achieve better consumption results and improve the behaviour of heating, cooling and ventilation.

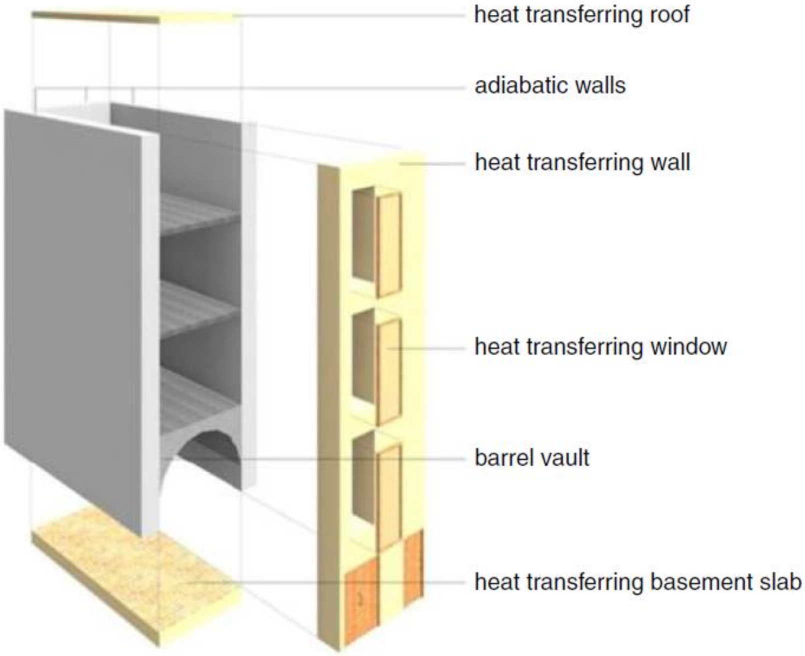

Figure 9 A virtual model of an 'illustrative' 'tower house' in Molfetta [12]

7.2 Performance assessment

In order to find the best combination of solutions, certain steps were followed. Firstly, a very deep analysis was performed, based on collected information from the archive and outer sources but also onsite tests, measurements and observations. The area of analysis was the typology of the building, the period when it was built, several properties related with energy like, thermal transmittance, consumption or solar radiation. The other areas of interest were more empirical, for example the materials used in the construction, general measurements of the building including the height and the number of floors but also the thickness and number of layers for each component. The heating to the building is provided by a gas boiler in addition with radiators and it is cooled with fans during the summer. However, this dissertation focuses on improving the energy performance of the building by transforming its envelope that is why it is assumed that the HVAC (heating, ventilation and air conditioning) systems will stay intact. Moreover, the analysis included a careful study of the modern requirements that a building should meet, for example maximum U-values or the restrictions of the area or a building that cannot be transformed.

All collected data were inserted into 'Design builder' software to get the actual values that the building and separate components present.

‘Design builder’ is a British software developed for buildings’ energetical assessment. This program is an example of a tool that can be used for analysing proposed solutions in a virtual way. There are several similar programs on the market but this one is going to be explained as an example of the possibilities that a tool like this can provide. Design builder is a licensed product and it can be used freely only for 30 days as a trial version. The interface of the software is very simple and easy to navigate, for any professional working with design programs before.

There are two ways of inserting a building in the program, either by inserting an already existing 3D model from another program or to create a new one inside Design Builder from scratch (example, Fig. 10) To create a model the software allows to choose a location of the project implementing all the meteorological data into simulation and after all the basic data is introduced, the program allows the user to build a model for the simulation based on the original building.

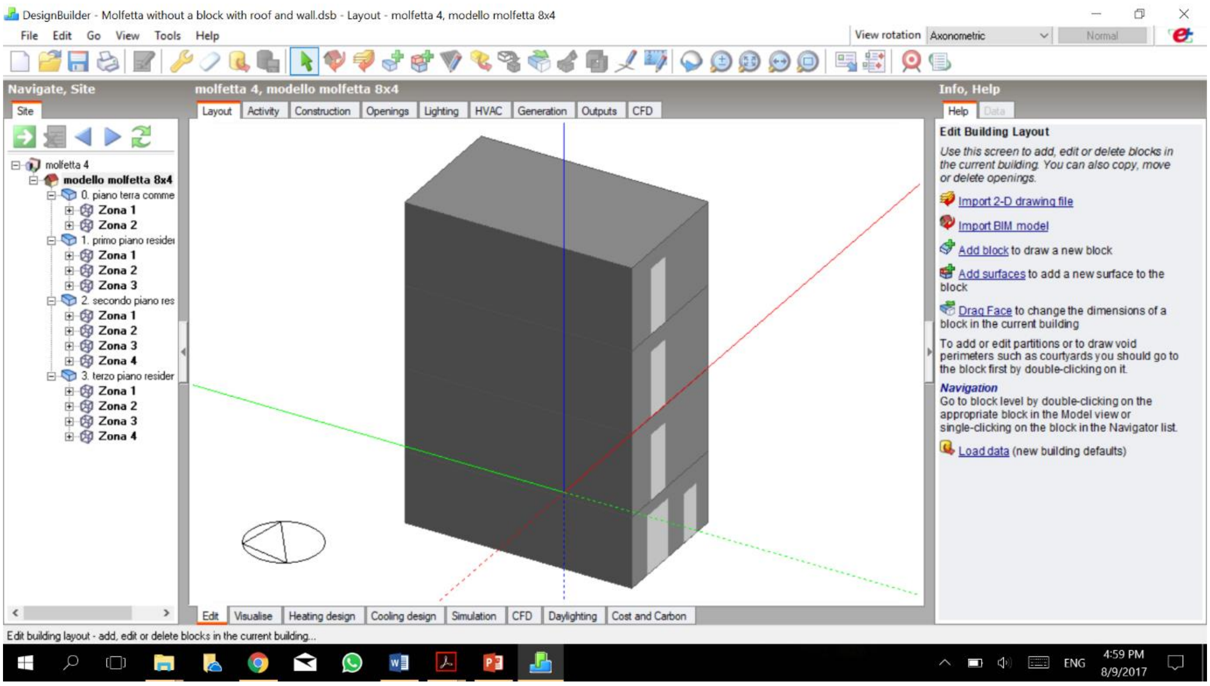

Figure 10 An example of a model created in ‘Design builder’ in this case a ‘Molfetta tower house’
Author’s own picture

Design builder has several templates itself and a library with popular materials and their properties. There is a possibility to modify every element, layer and material in the program or to create a whole new template for particular projects. Some companies also create their own elements that are uploaded to the libraries as a part of a marketing strategy. Designers can learn the efficiency and the properties of their product while performing the analysis and possibly choose it as an actual solution for the project. There are many setting options that can be adjusted and many results that can be achieved depending on the case and the purpose of the simulation. Things like energy, electricity usage, solar gains, temperature (air temperature, radiant temperature, operative temperature and outside dry-bulb temperature), ventilation efficiency, heating and cooling needs can be measured and estimated after inserting all necessary data.

Design builder is a complex program that also considers human activity and the purpose of the building. It contains fields that can be considered crucial factors in some areas, for example the number of people that use the building, what kind of activity they perform, the equipment that is used or desired temperature in the rooms that affects heating and cooling estimation. The software is very flexible when it comes to materials choice. Every component can be selected separately or created accordingly to certain properties (Fig. 11).

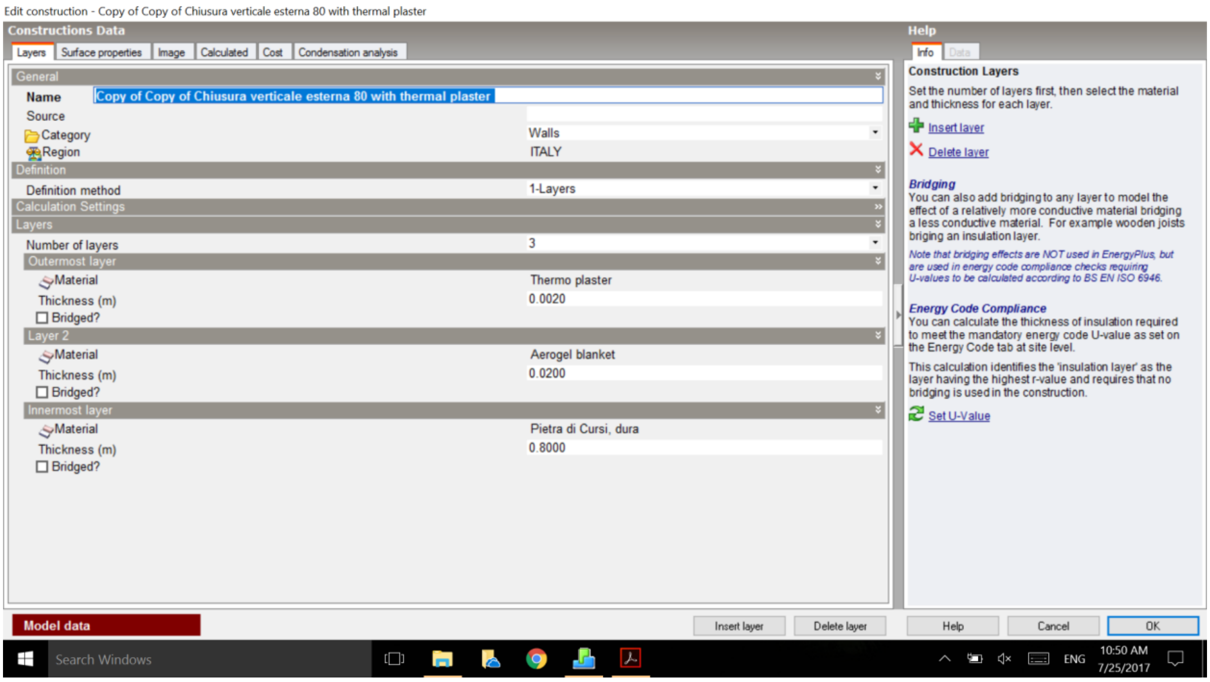

Figure 11 Window in 'Design builder' that allows change the components properties and dimensions
Author's own picture

While creating a particular construction there is an option to select a certain component, copy it and modify it a layer by layer. Properties of every one of the layers can be introduced separately, creating a unique component designed for this project. When the component is adapted to the need of the case another criterion can be set. An example of the practical options program gives is the setting of geometry of the component including the area and volume, thermal mass, air tightness and thermal bridges. Depending on the available data there is a possibility that design builder will calculate the cost of either the separate component or other needed elements of the project. There is a wide range of solutions Design builder can process including modern, sustainable solutions like implementation of different types of phase change materials or conversion of standard roof into a green roof. Openings can be managed in a comparable way as other component (figure 12). It can be chosen from a library or created and adapter accordingly to project's needs. All settings like dimensions, frame type, shading, airflow control and vents can be changed. Doors, skylights and other openings are included in and can be modified in this field.

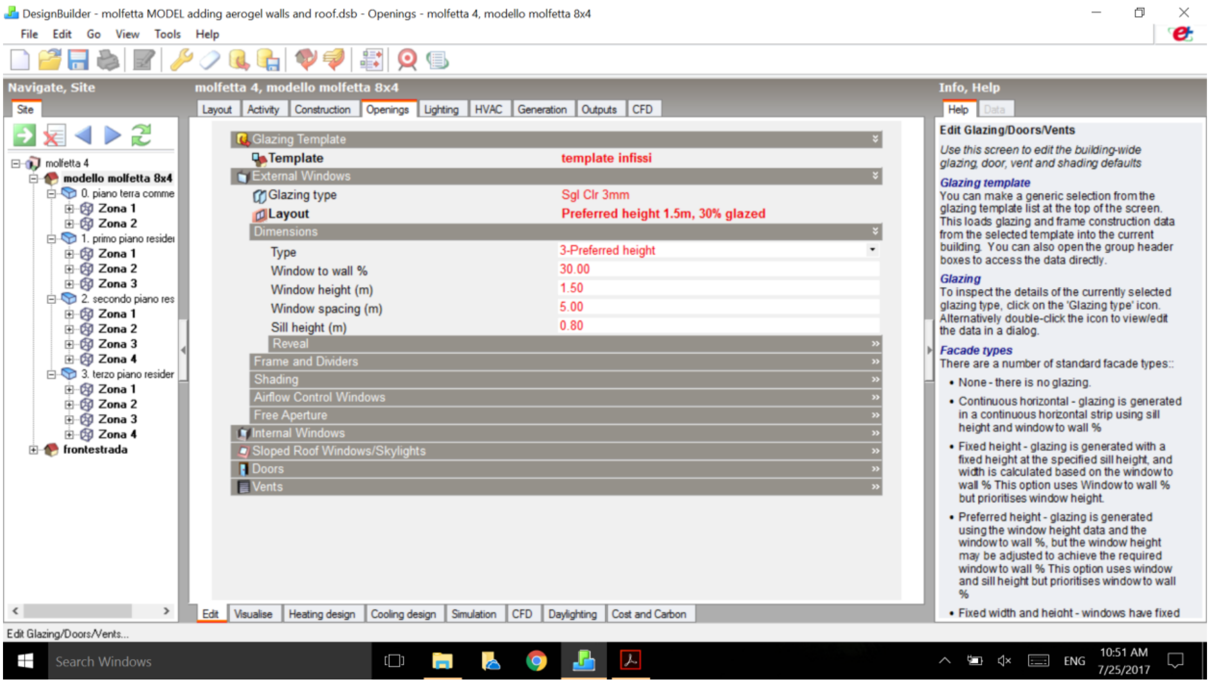

Figure 12 A window in 'Design builder' that allows controlling openings' settings
Author's own picture

Moreover, lightning and HVAC (heating, ventilation and air conditioning) systems can be designed and tested as a part of a simulation performed by Design builder.

The main way to use the program is to build a model with the original data, perform a simulation and compare the results with the future outcomes after the improvements are implemented.

One of the techniques is to choose a combination of solutions and perform simulations in all different options. This gives valuable database that can be used as one of decision making factors while choosing the most compatible options. For example, compare the results after changing only windows with the ones where only roof construction was changed. Not always the same element is going to be the most suitable for renovation. Depending on the construction, budget and the materials that need to be preserved in an original state in relation to its cultural heritage. Design builder can not only help deciding which material is the best solution for the project but also which placement is the most efficient one. However, energy assessment can be an important analysis especially regarding renovation projects.

The biggest issue that the user can meet while working with Design builder is the problem with applying changes on all the levels and in all layers after implementing and updating the change. This problem can lead to performing a simulation with changes applied only on some parts of the building, achieving false results. Moreover, checking all the layers for potential failure after every change is very time consuming and frustrating for a user what can be followed by mistakes that could be easily avoided if program would apply changes automatically or accordingly to a pattern. Another issue that is confusing for a user is double tools option what can be also misleading while looking for a solution if any problem occurs. However, the program works well for the purpose it was created, allowing the user to assess the performance of the building or an element, showing how efficient the solution is and how suitable it can be for the renovated building. Sometimes too high impact renovation can have an impact on the sensitive inner climate of a building, what is a crucial issue in this type of projects. It can be controlled and analysed using the data achieve from Design builder's simulations, checking data like humidity level, ventilation flow or inner temperature. An example of simulation's results are presented in a picture below (Fig. 13)

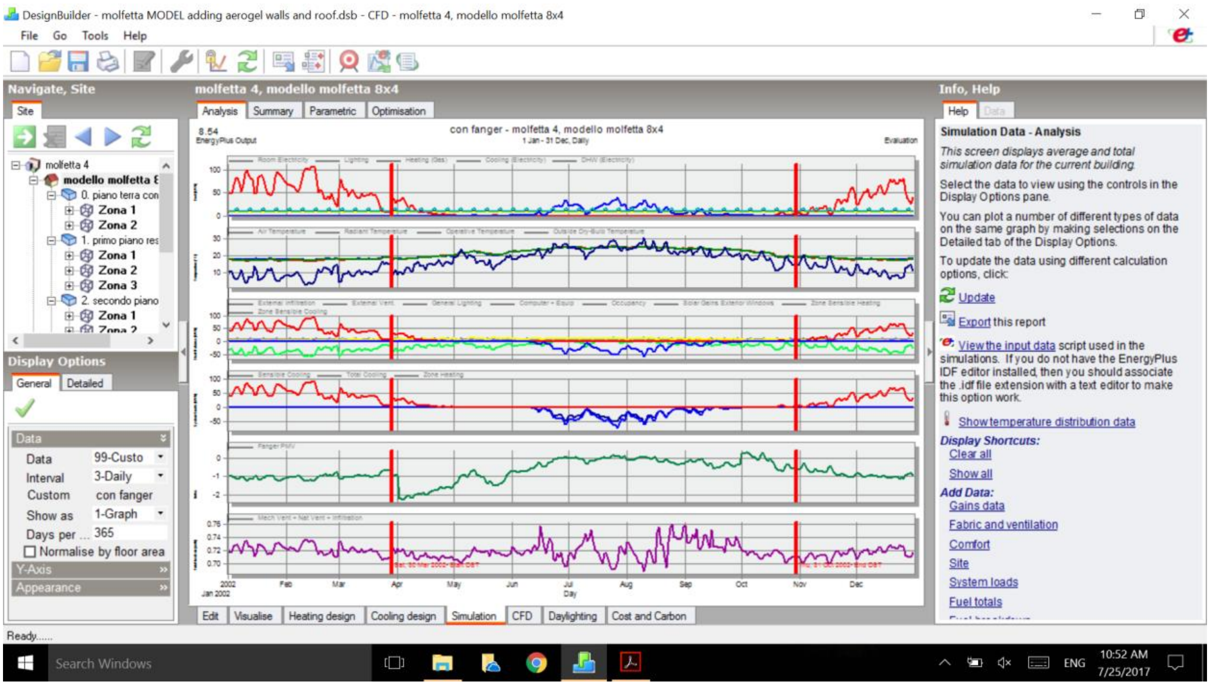

Figure 13 Simulation results in a graph form from 'Design builder'
Author's own picture

Nowadays, virtual assessment is a designing step that cannot be missed. Construction demands and the goals that should be achieved cannot be reached without previous analysis and there are too many factors, as described above that have an influence on the achieved results. It is also a useful tool to check smaller things like the market's offer for the most suitable solutions that can be tested in consideration of a specified case and not producers' general recommendations and assurance. Therefore, energy assessment software help finding not only the most suitable solutions but also the ones that are the most environmentally friendly, what is a general long-term goal.

Because the other buildings are built very close and strongly affect the results of the simulations it was beneficial to prepare a few models that include the buildings that are attached to the analysed one but also the ones that are in front of it, affecting the sun exposure and heat storing. Another crucial factor was a placement of the building accordingly to its orientation in order to achieve the most reliable values but also the ones that are the closes to the actual condition. Every single component was implemented and analysed separately to get the idea of their behaviour, advantages and disadvantages they bring. This kind of information gives an idea of the areas that need the most focus or the highest degree of transformation. Moreover, this way the restrictions that the protection of the cultural heritage or value is represented can be also analysed and balanced out with the alternative components.

After the collected data was implemented into the model and correct properties set, the simulation was requested in a location the closest to Molfetta with all weather and climatic data taken under consideration. This proceeding guarantees the closest to reality results what is a key to prepare the most useful consideration.
At first the simulation was performed on the building itself to understand which components are the least efficient and to receive the actual heat transmittance results, not affected by the external factors. Then the second sequence of simulations was performed with the buildings attached to the analysed one. This is necessary because in the previous simulations the 'side' walls were understood by the program as external walls what gives slightly different values when the changes are applied. The final series of trials on the original construction was performed together with a building from the other side of the street. This change allows the program to understand which parts of the 'tower' building are naturally protected from the sun exposure. It affects mostly the windows' performance but also the amount of heat stored and transferred through the walls. The following step was to perform the same analysis but with an addition of the proposed improvements to the building. Figures 14 and 15 show a comparison of different results depending on applied data.

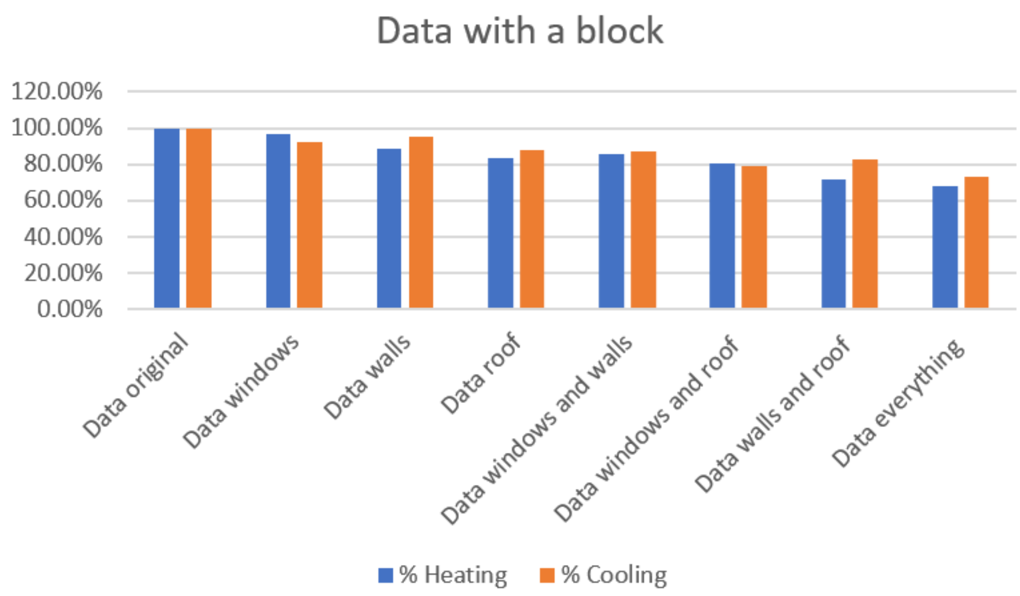

Figure 14 A diagram showing the comparison of percentage results from 'Design builder' without an implementation of the bloc in front of the building.
Author's own picture

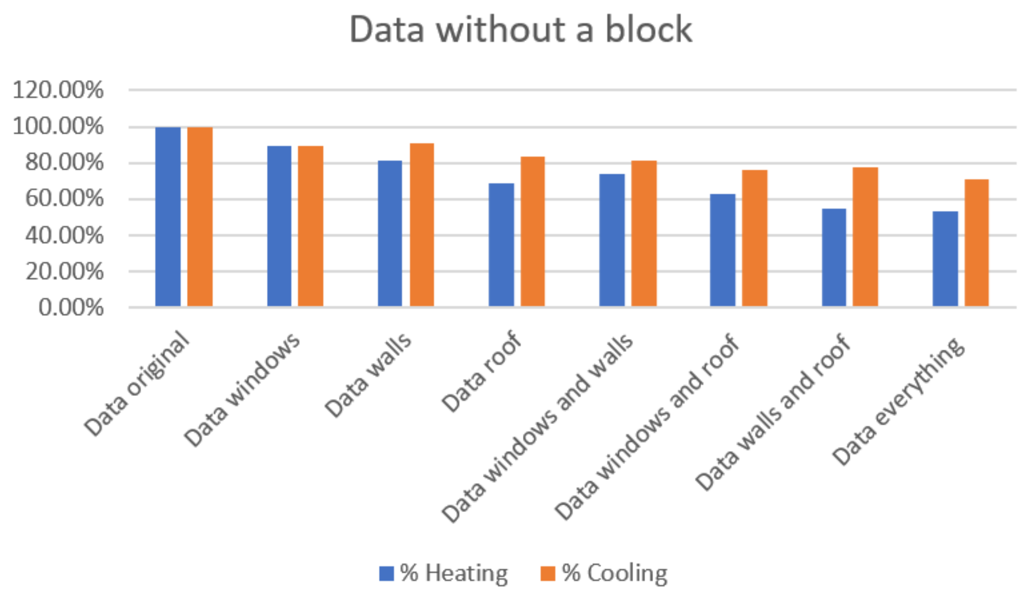

Figure 15 A diagram showing the comparison of percentage results from 'Design builder' with an implementation of the bloc in front of the building.
Author's own picture

This type of analysis can show the advantages and disadvantages of every solution or material. The recommended way of performing simulations is time consuming but provides values that can be collected and compared in one data base during final decision making. This way is based on performing simulations of different configurations, for example check the results of energy performance only after applying changes to the roof structure or only roof and windows. Then the results can be compared in a file based on the values of cooling and heating loads. The same technique can be used to test the performance of proposed materials, for example apply the vacuum insulated panels and then compare it with a result of aerogel boards. Every component must be tested with all considered solution in order to find the most suitable one. Moreover, all possible combinations shall be tested to discover the ones that are the most profitable and match the needs of the intervention. In this case study, the results showed that the most beneficial impact will give the roof transformation that showed 31% savings on heating and 16.5% on cooling. The following result was achieved by the walls with 19% of savings for the heating and 9% of savings on cooling. Obviously, the best result would be achieved by replacing or transforming all the components. However, the results show that certain values can be achieved by transforming only some of the elements. This kind of simulations shows if desired values can be reached and with what kind of transformation degree. Also, the U-value demand is an indication for the necessary improvements. But, accordingly to the results the main focus should be on the roof and walls in order to achieve the most satisfying energy savings. Figure 16 shows the results achieved by the simulations and the U-value demands and the U-values achieved by the implementation of proposed solutions. All the simulations were performed only with solutions that are feasible regarding the preservation of cultural heritage or value.

With a block	Heating	Cooling	% Heating	% Cooling	U value demand	U value achieved
Data original	9084.16	1606.21	100.00%	100.00%		
Data windows	8796.49	1485.96	96.83%	92.51%	2.4	2.05
Data walls	8064.37	1533.89	88.77%	95.50%	0.38	0.283
Data roof	7581.75	1405.13	83.46%	87.48%	0.36	0.359
Data windows and walls	7772.69	1402.77	85.56%	87.33%		
Data windows and roof	7278.17	1267.19	80.12%	78.89%		
Data walls and roof	6506.37	1325.49	71.62%	82.52%		
Data everything	6193.56	1173.9	68.18%	73.09%		
Without a block						
Data original	6292.61	1798.22	100.00%	100.00%		
Data windows	5640.09	1611.11	89.63%	89.59%		
Data walls	5097.57	1632.25	81.01%	90.77%		
Data roof	4322	1502.41	68.68%	83.55%		
Data windows and walls	4647.72	1458.43	73.86%	81.10%		
Data windows and roof	3945.97	1370.82	62.71%	76.23%		
Data walls and roof	3409.82	1393.44	54.19%	77.49%		
Data everything	3335.73	1279.67	53.01%	71.16%		

Figure 16 A table showing the results achieved from the 'Design builder' simulations. Author's own picture

Because the roof is the most exposed structure the application of phase change materials should be considered. In a case like this when the temperatures during the summer raise a lot changing the thermal inertia could be profitable for the comfort inside of the building. This kind of a material can be implemented in several separate ways on several different layers. That is why a proper virtual analysis shall be performed in order to locate the most efficient place for the phase change materials application. Since the temperature peaks are very high during the summer, considering the placement options should be done. Every phase change material product has the temperature point where the phase change is performed. In order to use the material's properties, the in its maximum capacity the average temperature should be close to the phase change one. This can be achieved for example by placing the phase change material product below or above the insulation level. This can be checked and measured also in 'Design builder' and the efficiency of this type of construction can be evaluated.
However, depending on a type of the product but also the structural reasons not all the placement positions are possible. In order to achieve the best results performing several simulations with all the possible options should show the most optimum results.

The following step was to research the available solutions and all the options were considered related with materials shown in one of the previous chapters. The proposal for the 'tower house' in Molfetta is based on market research and deep analysis performed in Design builder. There were compared several options and materials combinations in order to find the most optimum solutions depending on a wall type. If a wall is made of a pure solid stone blocks the options are limited to minimum because the original look of the stone must be protected. Then the designer focuses on other components of the envelope trying to achieve the best results without impacting the original construction. If the wall is made of two stone outer layers with a cavity in the middle that is filled then there is a possibility of replacing it with another material with a higher performance. Or mortar with PCMs. The placement of insulation depends on the analysed case. If a wall is plastered there is an option of placing it on the outside if the architectural values of the building stay intact. If the geometry of the building is a critical issue but it is still possible to place insulation outside the option worth considering is aerogel. If outside layer is not plastered or the thickness cannot increase then the insulation must be placed on the inside. However, might not be possible if there are some important paintings or frescos on the wall. Plastered walls give the possibility to replace the original layer with a thermal plaster. A thin layer of this high-performance material can significantly improve the efficiency of the wall. The most suitable option is to use a high-performance insulation on the inside and outside of plastered walls. The recommended products are vacuum insulated panels or aerogel boards. The disadvantage of the first ones is a high potential for damages what results with a lower performance. Also, the boards are not flexible and thicker comparing with aerogel what might be a key decision factor. Aerogel is a better choice for a project with irregular surfaces that might need to be adapted on the site. Walls insulation must be implemented to reduce the energy consumption spent on heating during winter season. The reason for insulating the wall from both sides, internal and external, is to prevent a significant reduction of rooms' functional area but also to keep the original shape of the building form the outside. Moreover, because most of the elevation is plastered this layer can be also replaced with a thermal plaster to increase the performance to the maximum potential.

Since the roof is the most exposed structure in the whole construction certain solutions were considered. The natural solution would be a placement of high performance insulation boards preventing high thermal transmittance. However, this type of insulation would increase the thickness of the whole structure raising the roof terrace level significantly. Another option that was considered was the implementation of phase change materials into the construction. The climate situation in that region and the high temperatures during the summer are a typical condition where implementing phase change materials is recommended. The insulation would reduce the heating consumption during the winter, insulating the inside temperature level from cooling down through the roof. The phase change materials would lower the air conditioning usage due to a thermal inertia shift creating the effect of a lower temperature during the day. The final solution designed for this case was to remove the top construction until the wooden beams in order to get and access for the improvements. The construction should contain a concrete layer with aerogel boards on top. Aerogel was chosen in this situation because of its high performance with a very low thickness. This benefit aerogel gives is valuable because it does not increase the height of the terrace, keeping the original shape of the building. On top of the high performing aerogel boards a water proof membrane shall be placed to prevent water and moisture penetration into the structure. It is particularly dangerous during the winter season when the rain and humidity level is high putting the building in risk for the humidity penetration into the roof and walls what might result with lowering the properties of the materials, weakening the structural performance of the construction and also increasing the danger of mould growth. On top of it the tiles would be fixed with a mortar mixture. It is recommended to implement a water based phase change materials into tiles. The straight exposure would result the most effective performance. The aerogel layer below would not block the abilities of the phase change from the top but limit the heat transmittance to the building. The stone tiles would be kept in the original style but the performance of the whole roof structure during the summer would be changed because of the phase change materials implementation. The whole structure was designed to keep the original look with the highest performance possible, without increasing the thickness or changing the visual presentation of the building itself. Other materials were considered but because of their lower performance or the construction demand they were rejected as not the best option for that case. However, this solution is very flexible and easily adaptable for the other buildings in that area and could be used in the following renovation plans.

Because the windows are relatively new and the performance of the building is slightly affected by their properties they are not the priority for the transformation. However, in order to reach a desired U-value for the modern demands certain changes must be made. The main options are to replace the whole windows with new ones but risking losing the visual qualities of the old ones and not matching the neighbourhood atmosphere. On the other hand, the energy results would be the best with this option. Secondly, the thickness of the frame should not be changed because it would require expanding every window opening gap and thickening it. This kind of intervention is possible but in this case not necessary because of it is highly invasive and not needed to be achieved desired properties. The second option is to keep the windows without any intervention since it is not crucial for the energy performance of the building. But as mentioned before the target is to meet modern requirements for the U-values. It is not only recommended because of the law but also to prevent repeating another intervention in a short period of time. The last option and the one recommended by the author is to keep the original frames and replace the glazing for the higher performance one and implement higher performance gas in between the glass layers for better insulation.

All the considered improvements were carefully researched and then analysed in ‘Design builder’ software in order to find the most suitable technological solution. Further studies should follow the specific price comparison in between potential materials and the amounts of products necessary for satisfying improvements. Very often the most suitable option is not chosen because of the high price, short life cycle, lack of availability, uneasy application or difficult maintenance. Projects concerned with historical heritage renovation are very often underfunded what significantly affects the design process and the following decisions. The whole decision process should be based on a support system with certain hierarchy and guidelines for the order of priorities. Moreover, this kind of projects require materials life cycle assessment to ensure that another intervention will not be needed in following years. The quality and long-life of products is a very sensitive matter in projects related with historical buildings renovation, because they are more fragile to changes and interventions than modern constructions. Moreover, the long product's life expectancy is always recommended, not only for historical buildings but also for modern construction to limit the amount of necessary improvements over the years to minimum. The case in Molfetta shows how complex and complicated a preparation for the renovation is especially if a historical building is an object of renovation. The restrictions and limited amount of solutions makes the task more difficult to design. However, this case was not an extreme type of a situation when most of the elements must be preserved and the intervention options are limited to minimum. It is an example of a standard project that can be relatively easily renovated and the solutions can be duplicated not only in the Molfetta district but after some modifications and adaptations to many buildings with a similar typology.

8. Conclusions

The case of Molfetta is an example of a traditional Italian building with a historical value for the region and the town itself. The atmosphere of the old town of Molfetta is created by charming streets and typical buildings made of standard, natural materials. The preservation of its natural character impacts the whole district of the Molfetta's old town. The modern solutions recommended for its energy retrofitting prove the potential of this type of materials allowing to meet required values while keeping the original shape of the envelope. It is an important ability, especially in a case like the presented one, where the narrow street limits the space of the transformation but also where the original look of the envelope has an impact on the surrounding area and the values it represents. The proposed solution shows the balance that can be achieved in the buildings with certain restrictions only by analysing the case and the options thoroughly. The project was designed using the innovative solutions analysed in previous chapters. The results achieved by improving the envelope show that a complete transformation is not always necessary and the performance of the building can be improved by evolving the envelope of the building by applying high performance materials or the combination of those solutions. However, the focus should not be only on technical solutions themselves but also on the methodology, the options assessment and a whole pre-design stage.

The need for improvements in existing building sector was proven by many organisations. Their concern about several factors like energy usage, CO_2 emissions, historical value preservation and environmental impact became a basis for new directives established by European committee. This dissertation mentions that the increase of energy usage grows yearly. The implementation of renewable energy does not lower those values sufficiently. However, the existing buildings sector with a focus on historical buildings is a gap that does not need to implement corrections in the process of creating those buildings that can be applied in ongoing and future projects, but needs a transformation of actual, existing construction. The paper shows the difficulty that is a balance in between necessary improvement in relation to energy retrofitting and preservation of the cultural heritage that a building represents and shall be a priority during a decision-making process. This paper highlighted that the improvement process must include various, balanced stages controlled by a well prepared methodological approach. The complex approach should involve a preliminary assessment that includes environmental, technological, energy consumption, architectural and constructional characteristics. As shown above the approaches vary slightly depending on their area of focus. The ideal option should be the most complex ones, however, sometimes a process can be shortened if one of the factors like heritage preservation, cost or availability of resources is limited. Then some of the others might not be relevant or less important for the assessment. The intervention shall be planned and designed based on the current building's behaviour and be balanced between the restrictions and the cultural value it represents. The proper evaluation might be a reliable decision-making support tool, limiting the possible mistakes. The comparison of intervention options and energy retrofitting possibilities should be based on a smart and complex system. That system should also help estimating the level of necessary improvements and the transformation degree of the envelope, based on the energy requirements balanced with the preservation of the cultural heritage. The analysis should be combined with virtual simulations, to estimate the results in an efficient way. Computer programs limit the validation time, help predict the results and predict the energy behaviour of every element and the actual materials' properties. This type of a reliable assessment leads to prioritizing the steps that can be taken during the intervention and deciding on a choice of the most optimal solution for every case. The virtual simulation can also help designing a linked together action process without dividing it into separate not related and planned stages that affect the renovation period, budget and the quality of performed work. The unification of decision making support system should not only relate to construction companies and designers but to all stakeholders including administration and public services. Improving the decision-making stage and permissions application would also encourage more investors to put their resources into the historical renovation part of the industry that is the most difficult to improve. However, this kind of a change would require creating a unified law in all European Union countries, with a special focus on historical buildings and the execution of implementing a new system in all participating countries. This kind of a strategy could improve the cooperation in between countries during international projects and additionally support renovations and better maintenance of already existing buildings.

Nowadays, the process of retrofitting can be achieved in more efficient way, improving the quality of intervention, but also limiting the degree of transformation in building's envelope. The use of modern technologies allows to predict the results before the changes application but also to achieve satisfying outcomes without significant changes comparing with traditional building materials. The number of viable solutions is not limited to standard procedures but present several, variable options creating a very wide and flexible range of possibilities. The potential of use of modern materials in historical buildings creates a necessity of developing new and higher performing products. The close relation of those two brunches of the industry creates self-developing market supporting the economic situation in both fields. Products like phase change materials present a solution that changes the view of the workability of buildings. It opens the project for new options and allows certain flexibility while working with heating, cooling and ventilation systems, lowering their energy usage at the same time. This type of cutting-edge products requires valuable analysis and simulations before the application because the sensitive inner climate of historical buildings is based on a balanced behaviour of all components and building's elements. However, the advantages achieved from using this type of a solution are very profitable for the future functioning of the building, including the energy usage and its environmental impact. The purpose of this paper was to prove that implementation innovative building solutions must be considered for every project that involves historical construction, especially considering the challenge that is the preservation of cultural heritage. However, the preservation of the cultural value supports the social education and historical awareness. The better condition of historically meaningful places is more attractive for the citizens and tourists, making the accessibility to historical knowledge easier to approach and receive. It also teaches the necessity of proper maintenance of newly or recently buildings preventing similar issues in the future.

References

1. Agency, I. E., 2014. *Key world energy statistics.,* s.l.: s.n.

2. Ahmed, A., Mateo-Garcia, M., McGough, D. & Gaterell, M., 2017. Methodology for Evaluating Innovative Technologies for Low-. *Energy Procedia,* Volume 112, pp. 166-175.

3. Barbero, S., Dutto, M., Ferrua, C. & Pereno, A., 2014. Analysis on existent thermal insulating plasters towards innovativeapplications: Evaluation methodology for a real cost-performancecomparison. *Energy and Buildings,* Volume 77, pp. 40-47.

4. BASF, 2017. *BASF We create chemistry.* [Online]
Available at: https://www.basf.com/en.html
[Accessed 29 08 2017].

5. Carbonara, E. & Tiberi, M., 2016. Comparing energy improvements and financial costs of retrofitting. *Energy Procedia,* Issue 101, p. 995 – 1001.

6. De Fino, M., Scioti, A., Cantatore, E. & Fatiguso, F., 2017. Methodological framework for assessment of energy behaviour of historic towns in Mediterranean climate. *Energy and Buildings,* Volume 144, pp. 87-103.

7. Del Bianco Foundatione, R., Hermann, C. & Rodwell, D., 2015. HERITAGE SIGNIFICANCE ASSESSMENTS TO EVALUATE RETROFIT IMPACTS:FROM HERITAGE VALUES TO CHARACTER-DEFINING ELEMENTS IN PRAXIS. In: *How to assess built heritage? Assumptions, methodologies,examples of heritage assessment systems.* Lublin: s.n., pp. 169-190.

8. Demertzi,, M., Sierra-Perez, J., Arroja, L. & Amaral Paulo, J., 2017. Environmental performance of expanded cork slab and granules. *Journal of Cleaner Production,* Volume 145, pp. 294-302.

9. DUPONT, 2017. *DUPONT.* [Online]
Available at: http://www.dupont.com/
[Accessed 29 08 2017].

10. Edsjø Kalnæs, S. & Petter Jelle, B., 2014. Vacuum insulation panel products: A state-of-the-art review and future. *Applied Energy,* Volume 116, pp. 355-375.

11. Fatiguso, F., De Fino, M. & Cantatore, E., 2015. An energy retrofitting methodology of. *Management of Environmental Quality: An International Journal,,* 22(984-997), p. 6.

12. Fatiguso, F. et al., 2015. *Energy models toward the retrofitting of the historical built heritage,* Bari: s.n.

13. Filippi Oberegger, U., Roberti, F., Luchi, E. & Troi, A., 2017. Energy retrofit and conservation of a historic building using multi-objective optimization and an analytic hierarchy process. *Energy and Buildings,* Volume 138, pp. 1-10.

14. Galán González, A., Bouillard, P. & Acha Román, C. A., 2015. TCS Matrix: Evaluation of optimal energy retrofitting strategies.. *Energy Procedia,* Volume 83, pp. 101-110.

15. Kuznik, F., Johannes, K., David, D. & Roux, J.-J., 2011. A review on phase change materials integrated in building walls. *Renewable and Sustainable Energy Reviews,* Volume 15, pp. 379-391.

16. Martínez-Hervása, M., Sendraa, J. J. & Suárez, R., 2017. Towards an Energy Assessment on an Urban Scale for Retrofitting. *Procedia Environmental Sciences,* Volume 38, pp. 688-695.

17. Martínez-Molina, A., Tort-Ausina , I., Cho, S. & -L, J., 2016. Energy efficiency and thermal comfort in historic buildings: A review. *Renewable and Sustainable Energy Reviews,* Volume 61, pp. 70-85.

18. Stahl, T., Brunner, S., Zimmermann, M. & Ghazi Wakili, K., 2012. Thermo-hygric properties of a newly developed aerogel based insulation. *Energy and Buildings,* Volume 44, pp. 114-117.

19. Tyagia, V., Kaushik, S., Tyagi, S. K. & Akiyama, T., 2011. Development of phase change materials based microencapsulated technology for. *Renewable and Sustainable Energy Reviews,* Volume 15, pp. 1373-1391.

20. YTONG, 2016. *Ytong Multipor Mineral Insulation Boards External thermal insulation composite system,* s.l.: s.n.