IOANNA TZETZI
STUDENT NUMBER : 4744527

Building Technology Graduation Topic
MASTER THESIS REPORT
P5

October 2019

Photovoltaic Technology & Heritage :
Towards the energy transition of the building environment

MSc4, TU Delft

Mentor Team:
1st mentor : Andy vd Dobbelsteen
2nd mentor : Wido Quist
3rd mentor : Zoheir Haghighi

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To my family...

Special acknowledgements to Athanasios Sertsis (Surveyor Engineer) and Maria Kirkou (Specialist in Heritage Preservation) for their vital help, to Maria Poritsa (member of the Cultural center of "International"), Georgios Antoniadis (chairman of the Cultural center of "International") for their connection with the building, to Eleni Pinopoulou (owner of "Diethnes") for her supply of data and maps of the building.

Special acknowledgements to my mentor team for their meticulously assistance and guidance to my path.

Special acknowledgements to Shweta Mahendra Kamble, Nimmi Sreekumar and Matoula Kounaki for their support and help.

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Summary

Reaching a neutral use of energy in the building environment is challenging. That is because, as the population expands, so does the energy consumption. Considering that the building environment is accountable for 40 percent of energy consumption and 36 percent of total CO_2 emissions, the building sector has to conform with specific guidelines and targets, in order to reach neutral energy use. Newly constructed buildings are already targeting better energy performance. However, more than one fifth of European building stock has been built before 1945, and together with low renovation rate in Europe, heritage buildings are struggling to become part of the new energy reality. In order to complete the energy transition, every sector of building environment should commit on energy saving and producing interventions. On one hand, by renovating heritage building stock energy is saved and buildings are performing better. On the other hand, it is challenging to apply energy production interventions in such buildings in order to balance the energy demand.

This introduction (Chapter 1) is the reason why, the current research is focusing on how photovoltaic technology could be applied on heritage buildings, without compromising their architectural character. The application guidelines, which are going to answer the latter question, are going to be tested on a heritage case study in Greece.

As a next step (Chapter 2), the legislative framework for energy transition is going to be described with the purpose to explore the extension of the guidelines, since they are covering all sectors of human activity. Additionally, the building stock in Greece is being presented and how the European legislative framework is applied in this country's concept.

Furthermore, in Chapter 3, the meaning of cultural heritage should be clarified and the legislative framework around protection and restoration should be explored. The reason behind this literature research is that heritage buildings are very specific cases with different values, and each case requires a unique approach. Regarding this subject, a focus will be made on strategic photovoltaic interventions from the Dutch and Flemish governments.

What is more (Chapter 4), photovoltaic technology is going to researched in depth, specifically how the photovoltaic cells are producing and how do they produce energy. Yet, some characteristics for better cell performance are going to be explained, such as orientation and energy yield.

Chapter 5 is the product of combining the previous Chapters, especially Chapters 2, 3 and 4. This Chapter get more explicit about solar interventions on heritage cases, such as where is the best place for the application and why. In addition to that, more criteria for suitable solar application on heritage are going to be researched, such as color, transparency, size and functionality.

In Chapter 6, several reference heritage cases are going to be studied and the data of the decision making are going to be gathered. With the latter, and based on literature research of Chapter 5, these cases are going to be evaluated on the "suitable" solar application and the varied important values for the decision making on the cases are going to be compared.

After the literature research on both heritage culture and photovoltaic technology, and also the applied version of them in reference buildings, a list of design requirements has formed. Therefore, the only way to test if these guidelines could be used for photovoltaic application in a random building, then it could be very valuable to similar future interventions. Thus, a heritage case building in Greece, specifically in the city of Florina of north-western Macedonia.

In Chapter 7, the choice of the building is going to be analyzed, since it is a true representative of Neoclassic architectural movement in the area and a landmark for the local community.

Regarding the design process, in the next Chapter (Chapter 8), the photovoltaic application is going to be analyzed based on the design requirements of the technology upon heritage and the specific demands of the building case. Supplementary to design guidelines, a matrix is formed in order to present all the different options for the interventions. By the end of the matrix, two energy scenarios are forming in order to perform the application in situations as close to reality as possible.

Regarding the design, public opinion upon energy interventions is very valuable, and especially when it comes to solar application on heritage buildings. In Chapter 9, the acceptance of similar interventions is going to be discussed. In addition, and in order to have specific overview about public acceptance in the local community of this research case study, a questionnaire is going to be conducted. The results are going to be presented and the public's influence is going to be examined.

Ultimately, in Chapter 10, the final design proposal for the case study is going to be demonstrated and the different applications are going to be analyzed. Finally, an overview of the design proposal is being inspected, as far as it concerns the building itself and the urban environment in total.

To sum up (Chapter 11), general conclusions re going to be presented and also the limitations of the research itself. A few suggestions are additionally to be explored for investigation of future possibilities on the subject.

1. Introduction

1.1. Argumentation for the choice of studio

The means to energy transition of the building environment are in urgent need for the sources of energy and the way that we use the energy, generally, to be altered. Wise choices should be made to all aspects of life to transit smoothly into a new reality that is different from what society already knows.

However, the deadline is coming closer every day and drastic solutions should be found to enter the dawn of a new era. All cities, especially in Europe, were trying to decarbonize originally by 2030, and now by 2050 as the achievement of the objective takes a great level of effort (Energy roadmap 2050, European Commission, 2011). For this to happen though, all aspects of life should be included and solutions that are needed for the necessary emissions reduction should be invented.

For the building environment, more specifically, the scenario of high energy efficiency is the basic commitment e.g. new buildings should fit to regulations of minimum energy use and old buildings should be restored to meet the same criteria. In addition, new technologies are being invented almost every day to match the requirements of the scenario concerning the use of high renewable energy sources that the transition necessitates. ("Energy roadmap 2050 Energy," 2012.)

The studio's choice is to bridge the divide between new technologies as well as monuments. The monuments and especially listed buildings (see Terminology), as expected, are those that are more difficult to be altered, in order to fit to the energy transition reality and still be a functional in the building environment (Buyle, 2018). The technology that is going to be used in energy production is photovoltaic technology because these modules are more easily adapted to the urban environment instead of other green energy e.g. wind turbines. In addition, new technological developments are changing the way that the photovoltaics are known by introducing new properties to the modules, like thickness, elasticity, transparency and color, that make them even more adaptable.(Murgul, 2005)

After all, habits have to be changed. The way that people are thinking at this moment must change in a way which is going to create more opportunities in the future, and not make them less and less every day. The way that we use the resources, the gifts of nature and natural laws should be modified, if we want to believe and hope to the existence of future generations.

1.2. Research Framework

1.2.1. Problem Statement

Reaching neutral use of energy in every aspect of the building environment is a challenging task. In building environment are accounted 40 percent of power usage and 36 percent of total CO2 emissions (Enerda, 2018). New buildings that have already been built in the last few years or are intended to be built in the upcoming future, are planned and designed following the lines of energy saving and circular economy techniques, as they should by international regulations ("Energy roadmap 2050 Energy," 2012).

Buildings, however, which have already been in the same place for a hundred years or more, are less, or not at all, likely to follow the new technological innovations. More than one fifth of the European buildings have been built before 1945 and the renovation rate in Europe is only 0.4 to 1.2 percent (Hellenic Statistical Authority, 2017). These buildings are listed monuments and representatives of history and architectural color of the city and country. They are designed for a purpose and with a certain perspective which defines them as witnesses of the past giving the multicultural value to Europe itself .

Depending on history, architecture and importance, not all the listed buildings and monuments are possible to follow the energy transition. There are laws and regulations that have to be followed in every step from preservation to renovation, and also the use that is going to be given to it (Murgul, 2005). However, more recent built cultural heritage and some exceptions from the older ones, as they are going to be explained later on the reference case studies, can follow innovative steps in order to be restored in a condition that can be preserved for the future.

This study is going to investigate those buildings' opportunities that contribute to the energy transition of the building environment and how history could be preserved, simultaneously with the natural resources. Since these cases are very particular and unique one from the other, each case used different means and methodology in order to achieve the goals without damaging the architectural value. In this research, photovoltaic technology application is going to be investigated as energy production technique in different energy scenarios, since it is more flexible to be installed in the building environment than other energy saving techniques, like wind turbines (Hermannsdörfer & Rüb, 2005). In addition, recent technological innovations are a great aid to not altering the image of the building environment and keeping the aesthetic standards high by adding more properties to the modules in order to adapt better. Historic buildings can survive if maintained as living spaces and a part of the everyday life. Energy-efficient retrofitting is helpful for both consumers and for heritage collections for structural protection as well as for comfort reasons.

1.2.2. Aim of Research

The aims of this research are to explore and evaluate different sources regarding the thesis object, photovoltaic and heritage. The latter is going to happen through studying literature and methods of comparative cases of reference buildings that have previously been attempted. In the next step, a conclusion in guidelines is going to be useful in future cases. In a particular fresh case study, these guidelines will be used in order to demonstrate the viability of techniques and methods, and to confirm that the energy transition has no limitations and compromises. The assessment of the new design will be decided based on the benefits that the design provides while reflecting an architectural personality at the construction and the consumers.

1.2.3. Boundary Conditions

The study will concentrate on the following aspects:

- Reference building cases that had photovoltaic technology used upon them.
- The evaluation of the reference case studies will focus on:
  - o The place where pv technology has been applied.
  - o The construction in general (walls, windows, roof) but with the aspect of the place of photovoltaic application.
  - o The materials that have been used or imitated.
  - o If the architectural character is being compromised with the use of the photovoltaic technology.
  - o The visibility of the photovoltaic modules.

- Greece will be the key-country for the photovoltaic concept to be exported.
- The reference building of the final case study will be a neoclassical example of architecture in Greece. The findings and suggestions will apply to listed buildings in European nations with architectural character comparable to the tested case study.
- The design will focus on the places that photovoltaic technology can be applied (roof, facade and some additional elements).
- Thus, the renovation, that the case study needs, will not be an issue in this research, even though small changes in the interior space are going to occur.
- An integrated photovoltaic application is going to be the final product.
- The evaluation of the design will be made by following key points of guideline which reflects the original architectural character.

1.2.4. Research Questions

<u>Main objective</u>

Integrating photovoltaic technology on a listed building to support the energy demand while increasing the energy efficiency of it, via literature research of case studies and application simulation.

<u>Main research question</u>

How could photovoltaic technology be applied on heritage buildings, without compromising their architectural character ?

<u>Sub questions</u>

Application of photovoltaic technology

- What are the possible and most suited places to integrate photovoltaic technology on listed buildings?
- What criteria can be used to evaluate potential photovoltaic applications on heritage buildings?

<u>Evaluation of reference cases</u>

- Where is it feasible to install photovoltaic technology onto listed buildings?
- What are the characteristics that the case studies focus more on?

<u>Design</u>

- How versatile and adaptable the photovoltaic technology could be when applied to a heritage building example?
- What are the limitations to the photovoltaic design?
- What elements of the design can be combined with the photovoltaic modules in order to not decrease the original architectural character?
- How does the general public perceive the integrated photovoltaic application on a building with high architectural value?

1.2.5. Relevance

To begin with, this graduation project is a way of closing the energy transition circle in the building environment. Of course, there are more to explore with the help of technological means. However, this is a call to all those who are involved in the architectural field and have the urge to preserve the past for the future.

Achieving the rebirth of listed buildings in ways that are functional again for the building environment, has a great value to preserving the history and setting an example to the future generations. These monuments had a specific function and thus that is how we should encounter them.

As it was mentioned before, the specific study case in this research is just one of the examples of retrofitting listed buildings, by implementing photovoltaic technology. Even though the case is stated in a small city in northern Greece, Florina, the case sets a big example of how we could treat the past. This research sets the guide to combine new technologies with the ones that are considered “old” and “out-of-fashion”. Buildings with the same architectural style exist in Russia, Germany, Austria and Switzerland, and even there they were restored properly in a way that they are again functional and less energy consuming. The energy production was not a characteristic of the renovation plan and thus it might be necessary in the future in order to produce as much energy as possible (Birēs & Kardamitsē-Adamē, 2004). However, generally, this research aims to change the way that listed buildings are treated and can have wider impact on other architectural styles as well.

The buildings should not only use less energy, but to also produce it in every possible way in order to have a smooth energy transition, as it is stated in the European plan for 2050 (Energy roadmap 2050, European Commission, 2011) . Energy production photovoltaic techniques are going to be used because the cells are more flexible and adjustable in almost every surface and climate situation (Strategic Energy Technology (SET) Plan ANNEX I: Research and innovation actions Part I-Energy Efficiency JRC93058 Acknowledgements to Drafters and Contributors, n.d.). Especially when it comes to listed buildings, the use of them should follow regulations about aesthetics of the architectural features. Technology aids this task since there are developments nearly daily in the performance and appearance sectors.

“ Adaptation and reuse of vernacular structures should be carried out in a manner which will respect the integrity of the structure, its character and form while being compatible with acceptable standards of living ”

(ICOMOS, 1999)

Based on the literature studies and data analyses, the following steps will be taken:

- Further data analyses of the old and the modern approach is necessary to make solid conclusions on which future designs can be based.
- Further literature research of more case studies is important.
- After elaborating on energetic aspects of the retrofitting, the design of the photovoltaic installations is very important for the aesthetics of the building.

1.2.6. Methodology

Choosing the study case

The building is a 1920s structure and follows the Greek eclectic architectural movement, and especially the neoclassic form. The privately-owned building is a true representative of the movement in the area of western Macedonia, in Greece, in the city of Florina, and it is one of the listed buildings in the area (Greek Governmental Decree, N.1460/50). More specifically, it is qualified as a work of art and although it is culturally protected, the country and the local authorities do not have the resources to restore the building, as it is stated in a testimony by Maria Poritsa (2018). In addition, after the two World Wars and the Civil one, buildings such as the one in the case study, even if they belong in the monument list, are not usually owned by the Greek government, but by civilian families, who most of the time do not the economical funds to restore them properly (Bamicha.A, 2008).

The native approach is going to be a very important part, since I come from the city of Florina, and the local people open more easily to a familiar figure. In addition, from experience, I can understand the importance of the building itself and its vitality to be preserved. In addition, since this particular movement is represented in Greece but also in central Europe, the study case is going to be an example that can be replicated as it is or with small alterations to other similar cases (Birēs & Kardamitsē-Adamē, 2004).

Method description

The research is going to be based on literature studies of photovoltaic and heritage retrofits.

Firstly, technology upon photovoltaics is going to be studied. Different systems are being researched and new cuttting-edged photovoltaic technology is going to be investigated. At the same time, a literature study upon listed buildings is going to be conducted. The meaning of listed buildings and the regulations that preserve them, are going to be some elements of this investigation.

Secondly, older similar heritage cases are going to be studied in order to set the guidelines and the approach of these. The marriage of these two elements, listed buildings and photovoltaics, is a relatively new approach to complete the energy transition of the building environment. In addition, the stage of conservation of each heritage structure is different and depends from country to country. These are based upon the economical stage and development of the country and the ability to preserve heritage buildings.

In a further stage, a case study is going to be used as a complementary method of proof. The case study is going to be developed in two different building program scenarios, hotel and cultural use. Weather data from the environment and energy performances of the different building programs are going to be used as source for the design. The latter is a part of the process, since the building is planned to be reused in the building environment. Thus, two possible scenarios of building programs are going to be tested, in order to form the photovoltaic design of the retrofit and to fit better in the active urban environment. Since there is a lack of governmental funds, the two scenarios are providing profitable options to investments from possible investors.

As part of the case study, drawings and maps are going to be used. These have already been made by the people who built the structure and from those who tried to estimate the state of dissolution. In addition, old photographic archives and literature, where the building is being mentioned, are going to be used as resources in order to magnify the importance of it. Attestation of local people and authorities are going to help with the investigation of the old use and everyday life in the building and to judge the compatibility of the photovoltaic technology with the image of the structure.

Furthermore, personal autopsy is going to assist forming the final drawings of the structure. Surveying the building is one of the most important steps of the case study since there are no drawings that correspond perfectly to the existing situation.

The Software, such as Grasshopper and Designbuilder will be used, so as to test the unique energy scenarios. The structure is going to be modeled based on the surveying plans and drawings, and the restoration plan is going to be planned according to autopsy elements, like photographs and measurements. Building or technical data that cannot be acquired shall be estimated according to standards, testimonies and comparable projects.

At a first glance on the cases, it is noticeable that the public's opinion is an important aspect of the introduction and application of photovoltaic technology into a listed building. Thus, a questionnaire is going to be conducted and used within the local community in the city of Florina, in order to testify people reaction to the new addition in an iconic building. The results are going to show a different perspective of this particular application and the design is going to be evaluated. Also, research studies upon the public's acceptance of photovoltaic on heritage, are going to support the results.

Last but not least, the overall evaluation, conclusions and recommendations are going to complete the task of this research.

The final developed method and process (Figure) could be used for similar cases in Greece or Europe, but especially for further development of the area, since the building is one of many similar cases that could develop a grid with themselves.

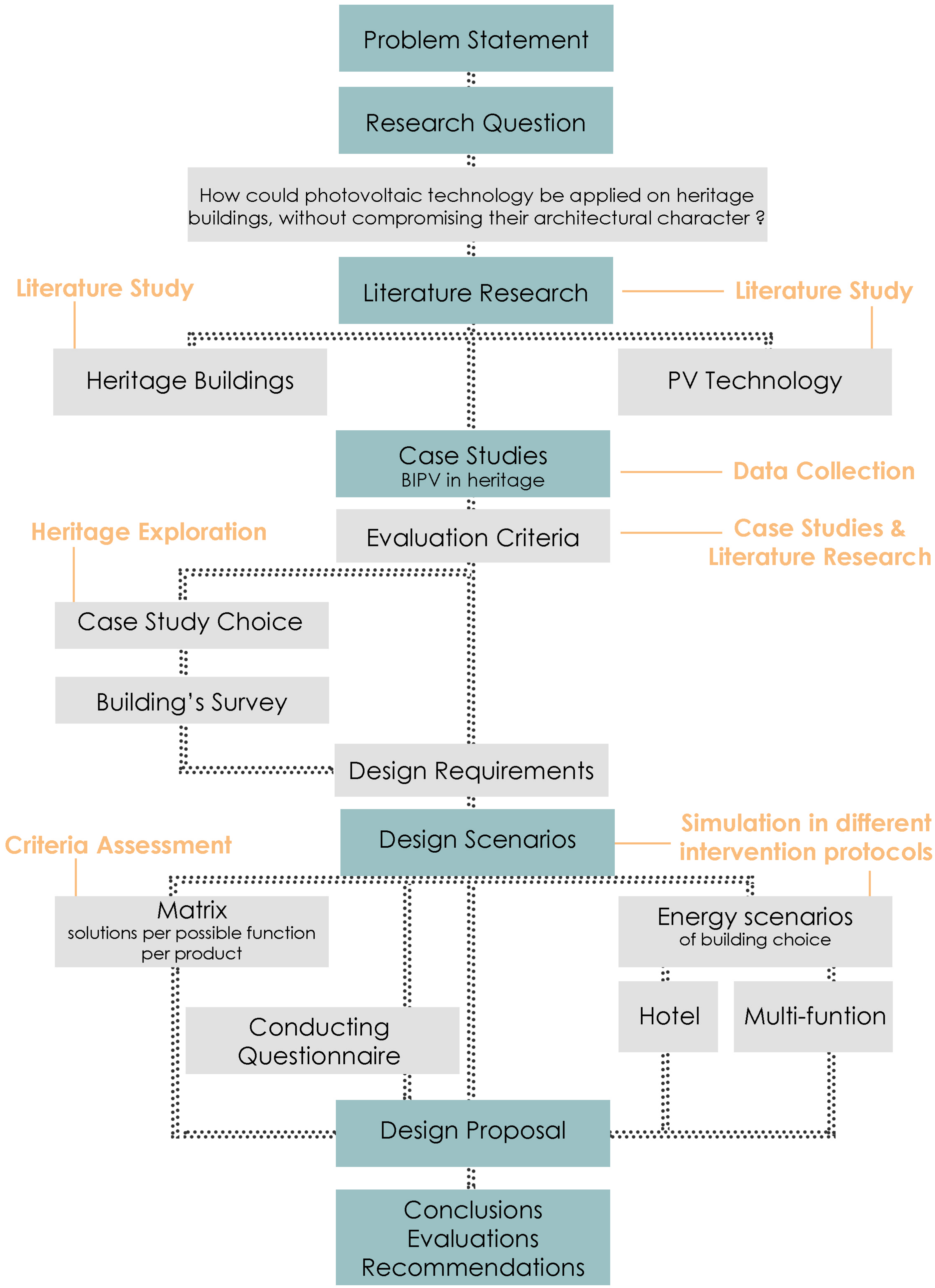


Figure (1) : Methodology Diagram

2. Energy demand in the built environment

2.1. Introduction

Climate change is a reality, not for a small group of people, but as a global phenomenon. It threatens with extreme weather conditions, such as heatwaves, hurricanes, floods and droughts, which become more and more spread and longer in period and in frequency. All these disasters not only cause economic damage, but also political instability, mass devastation and loos of lives. The reason behind it, is the human activity which enhance the normal global warming and overheats the earth.

By trying to reverse the overheating by 1.5^o C and modify human activity in order to be environmentally friendlier, maybe there would be hope for next generations to live in a livable planet. Therefore, immediate actions are vital.

More specifically, the used energy is the outcome of a long chain, which starts with mining fossil fuels, and has many negative stems, such as the overheating of the planet. That is the reason why is so important to modify human activity and consumption. Improving energy efficiency leads to reducing the energy consumption. In addition to that, the energy production would enhance the use of alternative energy sources in order to achieve energy balance.

In this chapter, energy performance and production in the building sector would be the main subject that will be analyzed, since this sector is responsible for almost 40 percent of energy consumption.

In this chapter, unfortunately, there is a scarcity of sources due to the fact that the only valid source was the wed site of European Commission. Any other source was not updated, like many cases found were not updated since 2014, and any other used research paper was referencing the same source as main one.

2.2. Legislative framework for energy transition

Buildings are responsible for approximately 40 percent of energy consumption and 36 percent of CO2 emissions in the European Union, making them the single largest energy consumer in Europe. In addition, at the present, about 35 percent of the European Union's buildings are over 50 years old and almost 75 percent of the total building stock is energetically inefficient (https://ec.europa.eu).

To boost energy performance of building sector, the European Union has established a legislative framework that includes the Energy performance of buildings directive (EPBD) (2010/31/EU) and the Energy Efficiency Directive (2012/27/EU). Together, based on the European Union plan, the directives promote policies which will help achieve a highly energy efficient and decarbonized building stock by 2050, will create a stable environment for investment decisions to be taken, and will enable consumers and businesses to make more informed choices for saving energy and money (https://ec.europa.eu).

In order to achieve a steady energy transition for everyone, businesses, governments and civilians, the European Union has set three Energy Targets for 2020, 2030 and 2050.

By the first target at 2020, it is aimed to reduce its greenhouse gas emissions by at least 20 percent, increase the share of renewable energy to at least 20 percent of consumption, and achieve energy savings of 20 percent or more. In addition, all European countries must also achieve a 10 percent share of renewable energy in their transport sector (https://ec.europa.eu).

By the second target at 2030, since there were slight changes, new aims where formed. These were a 40 percent cut in greenhouse gas emissions, compared to 1990 levels, an at least a 32 percent share of renewable energy consumption, and an improvement in energy efficiency of at least 32.5 percent. In addition, following the 10 percent of electricity interconnection target for 2020, it is aimed to reach 15 percent by 2030 (https://ec.europa.eu).

Finally, by the third target at 2050, greenhouse gas emissions are intended to be reduced by 85 – 90 percent, compared to 1990 levels, with the decarbonization of the energy system in order to be viable in the long run. A system that is encouraged to be adopted by European countries is the early replacement of the energy infrastructures, which would be replaced anyway due to their age, with low-carbon alternatives, which would cost less by 2020 based on predictions (https://ec.europa.eu).

Additionally, at the Paris Climate Conference (COP21) in 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. The agreement sets global actions in order to avoid life threatening conditions internationally due to climate change by limiting the global warming by 2^o C. This action plans would make societies deal with the impacts of climate change and provide support and economic boost to developing countries (https://ec.europa.eu).

Moreover, according to the European Union's framework, it is required that all new buildings from 2021, but public buildings from 2019, to be nearly zero-energy buildings (NZEB). According to Article 2 "nearly zero-energy building" means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including sources produced on-site or nearby. However, Greece has not yet defined a nearly zero-energy buildings (NZEB) in the legislation (https://ec.europa.eu).

There are no specific requirements for the Member States giving them freedom to define their nearly zero-energy buildings. That is because every country has specific climate conditions, primary energy factors, ambition levels, calculation methodologies and building traditions. In order to standardize this diverse situation in the building stock, European Union has set a project to achieve this. Project ZEBRA2020 sets a clear methodology for defying a zero-energy building by combining qualitative and quantitative data of building standards in a specific region. Thus, each country should select two of the four different radar clusters, which are : 1) net zero-energy buildings/ Plus-energy buildings, 2) nearly zero-energy buildings (according to national definitions), 3) buildings with an energy performance better that the national requirements in 2012, and 4) buildings constructed or renovated according to national minimum requirements in 2012 (https://ec.europa.eu).

The policy measures that have to be implemented in every country's legislation of the European Union, are based on the roadmap towards a zero-emission building stock. These include: 1) the encouragement of automation and control systems in the buildings, 2) the installment of smart indicators based on the users needs using new technological systems, 3) the investments on deep renovation in the building stock for better energy performance, and 4) the elimination of energy poverty from the households.

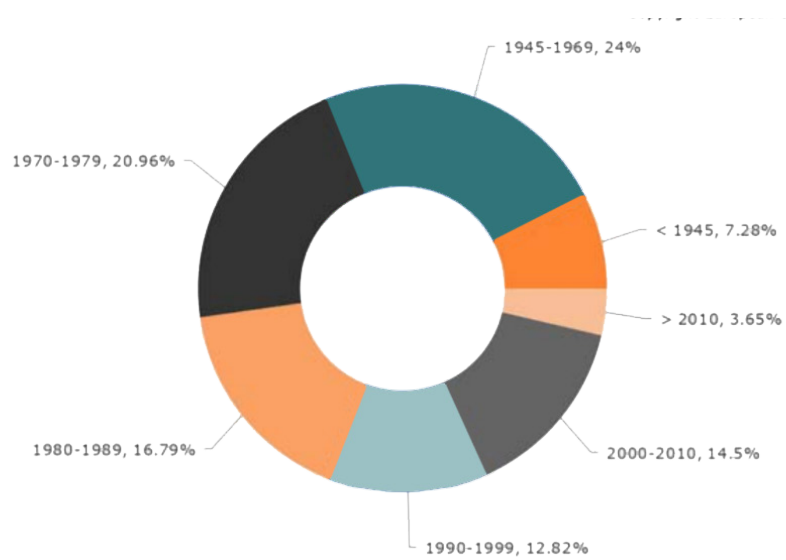


Figure (2) : Residential buildings according to construction rate (European Commission,2016)

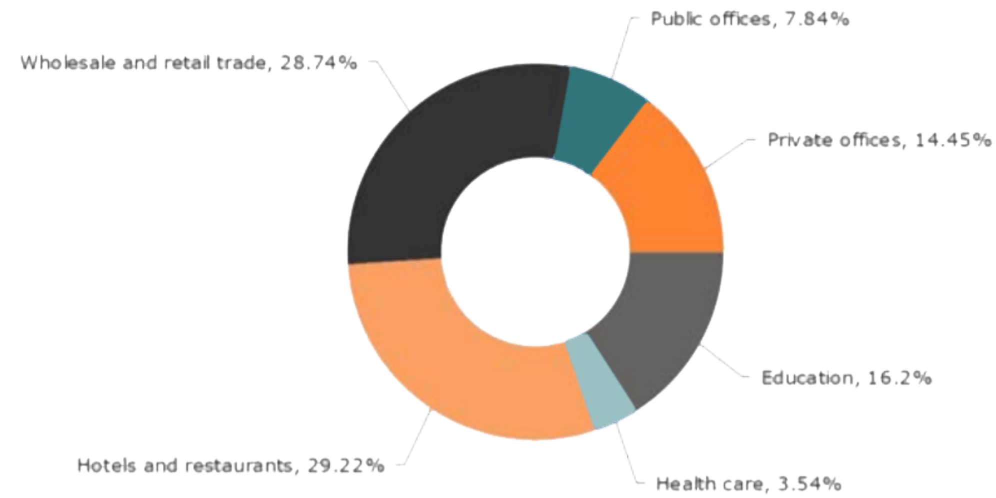


Figure (3) : Non-residential buildings by faction (European Commission,2016)

2.2.1. Renovation rate in Europe

The above energy plans aim to achieve the European Union's targets by boosting buildings efficiency together with long-term renovation. After an overview of the entire building stock of the European Union, policies and actions would stimulate cost-effective deep renovation of buildings, with residential and commercial function, with the worst energy performance or the most consumption because of public use. Moreover, smart technologies would act as additional elements to complete the transition (https://ec.europa.eu).

It is unfortunate that only 0.4- 1.2 percent (depending on the country) of the building stock is renovated each year. Renovation of existing buildings can therefore lead to significant energy savings and play a key role in the clean energy transition, as it could reduce the European Union's total energy consumption by 5 - 6 percent and lower CO2 emissions by about 5 percent (https://ec.europa.eu).

The strategy of renovation is going to include identification of cost-effective approaches relevant to the building type and climatic zone. In addition, an evidence-based estimation of expecting energy savings is going to be conducted and, also, the wider benefits are going to be assessed, such as possible investments decisions from individuals, construction industry and financial institutions (https://ec.europa.eu).

In addition to energy efficiency gains, renovated building stock can also create economic, social and environmental benefits for everyone. Moreover, it could contribute to the improved health, comfort and wellbeing of the residents by reducing respiratory and other illnesses caused by a poor indoor climate. All in all, homes are made more affordable and it would help households escape energy poverty (https://ec.europa.eu).

2.3. Building Stock in Greece

2.3.1. Building Stock Characteristics

The average age of buildings and the share of new buildings in the total stock represent good indicators of the average efficiency of the building stock: the higher the share of recent dwelling, especially built with more efficient standards, the higher the energy performance of the stock. According to European Union's data collection, 81 percent of Greece's building stock was constructed from 1945 until 2000 and the rest 19 percent from 2000 until 2010 (Figure 1). In addition, most of the public buildings are hotels and restaurants (Figure 2).

As it comes to the energy consumption in the building stock, according to the European Union's monitoring, the energy consumption in residential buildings is lower compared to the European average and in non-residential buildings is higher compared to the European average (Figures 3&4).

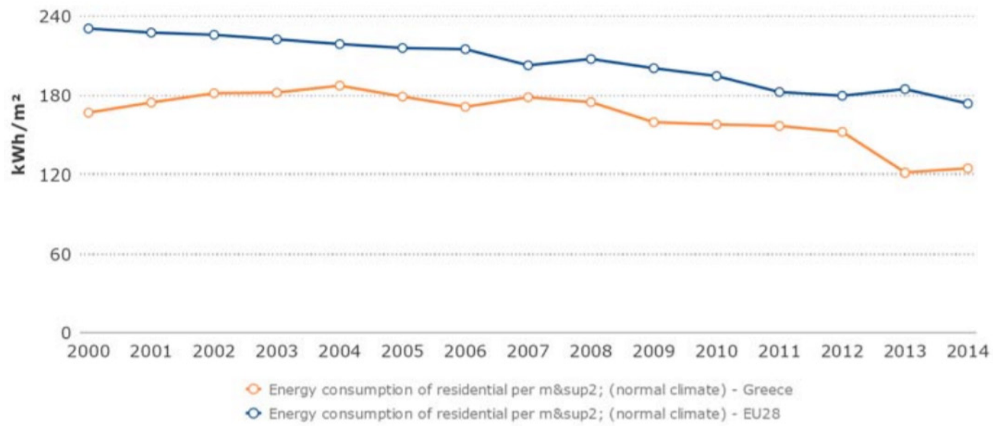


Figure (3) : Energy consumption in residential buildings (European Commission,2016)

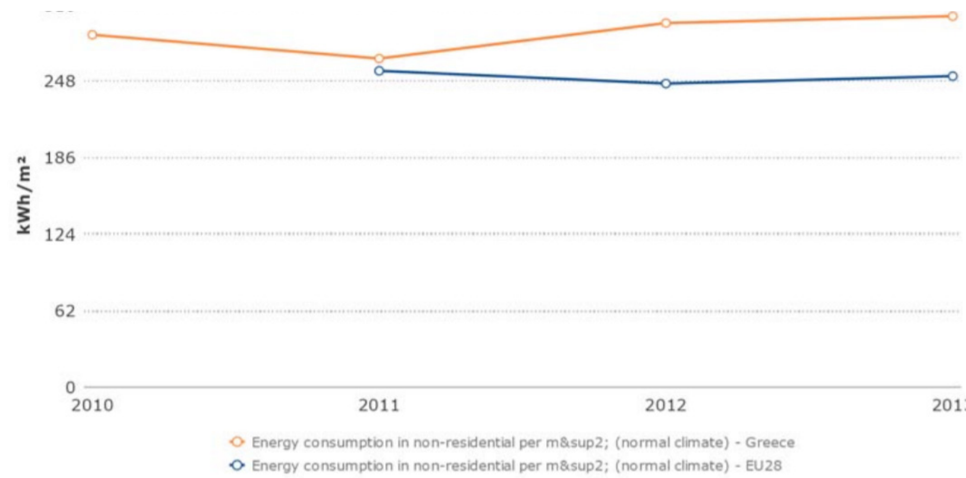


Figure (4) : Energy consumption in non- residential buildings (European Commission,2016)

Moreover, the energy consumption is based upon the thermal quality of the building envelope. However, since most of Greece's building stock was constructed before 2000, there are not many new implementations, which are directed from the European Union, to optimize the thermal performance, and that is the reason why refurbishment of these existing buildings is important for the quality of thermal envelopes. Thus, based on the European Union's monitoring, there were changes between 2008 and 2014 due to the combined effect of new construction and refurbishment of the existing stock and related national requirements (https://ec.europa.eu).

2.3.2. Current energy policy

Currently, Greece is dependent on the import of electricity which amounts to 65.3% and is ranked 8th of the 27 European Union countries in relation to its dependency on energy imports (Azam, Khan, Zafeiriou, & Arabatzis, 2016). Regarding the energy policy of Greece and following the energy crises of the 1970s, the country has formulated an energy policy based on lignite, which is the usual domestic electricity resource. Recently, natural gas is also being promoted, which however does not imply less dependency, but never the less differentiates the energy mix, with an undoubtedly cleaner fuel when compared to lignite and coal (Tampakis, Arabatzis, Tsantopoulos, & Rerras, 2017).

Nevertheless, and particularly at present, at a time of economic and environmental crisis, Greece should focus on energy savings, renewable energy sources and the rational use of conventional energy resources, since there is a significant and exploitable energy potential in renewable energy and can significantly increase their use. Thus, based on the target of the European Union, household energy saving programs made an appearance in 2011, which were economic incentives for energy-saving interventions in residential buildings aiming to reduce their energy needs. The eligible categories of interventions in order to improve their energy efficiency are: 1) the replacement of windows/doors (frames/glazing) and the fitting of shading systems, 2) insulation of the building envelope including the flat roof/roof and pilotis, and 3) the upgrading of the heating and hot-water supply systems. In addition, there are also several other initiatives for the promotion of highly efficient appliances, such as the change of the air-conditioning for a newer version. Simultaneously, there are also programs for improving the energy efficiency in public buildings and the awareness for public and private transport sector (https://ec.europa.eu).

2.3.3. Renewable energy

On the long run the building stock in European Union should be energy neutral, meaning that all the energy demand is covered by on-site renewable energy generation. The Renewable Energy Directive (RES Directive) establishes an overall policy for the production and promotion of energy from renewable sources in the European Union. It is required to fulfil at least 20% of its total energy needs with renewables by 2020, by achieving the target through the individual countries.

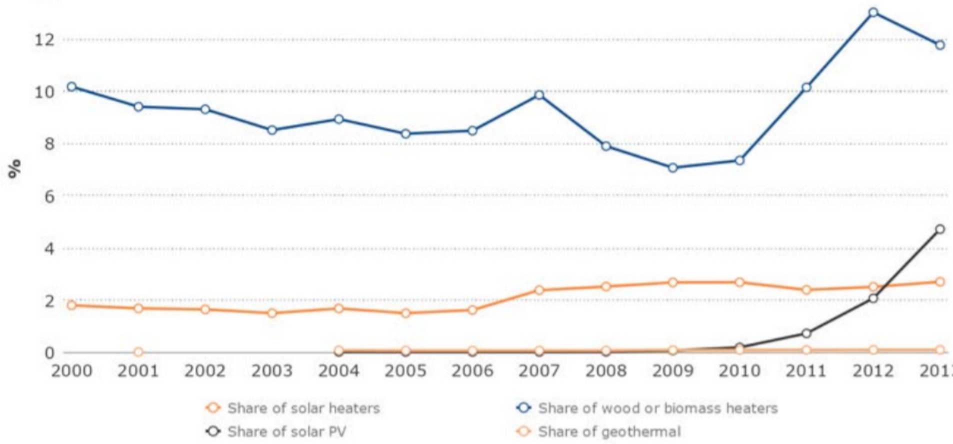


Figure (5) : On-site renewable energy generation (European Commission,2016)

Nevertheless, Greece has not set national renewable energy requirements per specific renewable energy source and it seems that the share of renewable energy generation compared to total final energy consumption of buildings is very low (Figure 5). However, the European Commission has set a target for renewable energy generation that influences Greek legislation. The target of 20.1% of renewable energy sources share in the gross electricity consumption by 2010 was set by the Directive 2001/77/EC. A few years later, in the European Directive 28/2009, the target of renewable energy sources share in the gross electricity consumption was further increased. This target was extended unliterally by the Greek government to 29 percent of the total electricity consumption (Mondol & Koumpetsos, 2013). Fortunately, due to an additional strong cost decrease of solar PV, since 2005 solar electricity production in Europe has grown with on average 56% per year (https://ec.europa.eu).

However, even that the renewable energy sources are a treasure for Greece, it is stated that an anarchic policy and the renewable energy sources installations and licenses have no strategic design, are usually of a large size in relatively small insular territories, and often violate several environmental or cultural constrains in the relevant legislation. Before 2008, applications and licenses were submitted in Greece without informing the local communities, which disregarded existing activities, and consequently challenged public opinion and reversed the generally positive public views for renewable energy sources. These applications presented a low level of maturity and in several cases involved a violation of environmental constraints, thus causing a great reaction within the local communities (Tampakis et al., 2017).

At the same time, the investment opportunities in the renewable energy sector in Greek islands are growing mainly due to available renewable energy resources. Moreover, socio-economic benefits could accrue by introducing appropriate strategies in relation to optimization of energy mix and supply of electricity to the islands, especially those with water scarcity. Because of the high renewable energy potential in the Aegean Sea, the proper introduction and application of innovative technologies could cover up to the total of the local energy needs, based on several studies on the implementation of various technologies for buildings in large islands (Mondol & Koumpetsos, 2013).

Thus, organized interventions have been suggested, that would be rational and based on municipal guidelines. With this way, local and national economy could be revived. In addition, it is believed that renewable energy investments are vital for Greece as an outcome from economic crisis (Azam et al., 2016). An example is the development of solar plant project HELIOS (http://helioscsp.com) which would attract more foreign investors which would stimulate economic growth of Greece (Tampakis et al., 2017).

2.3.4. Obstacles in realizing renewable energy interventions

There are many barriers when it comes to renewable energy interventions in every human activity, from implementation of programs, to achieving the energy targets.

First of all, the main barriers of renewable energy implementation into the European energy associations are the lack of legal framework for independent power producers, the complexity in the fuel price risk assessment, the transaction costs, the restrictions on sitting and construction, the subsidies for competing fuels, the high initial capital costs, the environmental externalities, the utility interconnection requirements, and the insufficient spatial planning.

In addition, specifically in Greece, the main technological barriers for the renewable energy sources implementation, are the poor grid infrastructure and the lack of detailed data illustrating the renewable energy potential of each zone of the country. Additional barriers include lack of clear national strategies evaluating the impacts of the renewable projects and the lack of financial advantages to support respective investments.

Furthermore, the main barriers in achieving the energy targets are the misguided interventions related to spatial planning for renewable energy sources, the lack of involvement of the local communities and authorities in the spatial planning procedure, the lack of awareness of citizens on relevant issues, the nonexistent legal framework relevant to the specifications of the facilities, and finally, the high electrical transmission losses.

As surveys have concluded, the slow pace of renewable in the focal economy is also due to the identified pre-elections and meta-elections slowdown, bureaucracy, which includes complicated administrative procedures and conflict interests between different ministry departments, and also, to a misalignment of information technology infrastructure between local and national level (Manolopoulos, Kitsopoulos, Kaldellis, & Bitzenis, 2016). Greece, after all, together with Hungary, is the country with the higher number of authorities involved in the procedure from production license to operation than most of the European countries.

As an action plan, proposed by WWF of Greece, should be planned the immediate priorities in two phases. In the first phase, the energy savings measures should be introduced in day to day life though the enactment of relevant legislative instruments ad by providing appropriate tax incentives. In the second phase, additional grants and incentives should be adopted especially in the lower social strata. Along with this new management structures and policies action planning groups must be developed for implementation of more innovative legislative initiatives

3. Cultural Heritage

3.1. Introduction

Cultural and natural heritage, in principle, is the treasure inherited from one generation to the next one and holds the history and identity of humanity. Thus, its preservation should be one of the most important aspects of urban life. However, many factors, such as the build environment itself, tourism and recreational activities, globalization and climate change, threaten to affect the properties and sites compromising the preservation efforts (https://whc.unesco.org). That is the reason behind forming different committees, calling conventions and situating charters and international agreements. The decisions concern every country, which should transform the guidelines of the councils into laws and regulations that should correspond to different regions and identities, but always keeping the originality of each one.

Furthermore, these days, that climate change is a major global concern, the necessity of including heritage buildings into the functional build environment is more pressing more than ever. This action, though, should be inside this specific framework that includes all heritage. Thus, the challenge for conservation into the new technological reality becomes even harder than before.

This chapter will identify the meaning of cultural and natural heritage and describe the context in which conservation is created. Moreover, new versions of guidelines, which obey to the older conservation framework but also include heritage buildings into the energy transition efforts, will be presented.

3.2. Cultural & Natural Heritage

Considering the importance and vitality of cultural and natural heritage, while threatened with destruction by many factors such as economic and political conditions, globalization and natural disasters, in November 1972, the World Heritage Committee, adopts a series of decisions, which are considered as milestones for the protection of cultural and natural heritage (https://whc.unesco.org).

To begin with, the definition of cultural heritage has been designated by UNESCO. cultural heritage is considered the monuments, group of buildings and sites, which have a universal invaluable estimation from historical, ethnological, anthropological, artistic, aesthetical and scientific point of view. In addition, as natural heritage is considered natural characteristics, geological and physiographical configuration, and natural sites, which are beyond value of conservation and natural beauty.

As follows, the Convention was proposed that each country should form guidelines and regulations which would protect these territories or specific buildings in order to prevent destruction and demolition. In addition, scientific and technical sectors should surround this effort to detect threatening conditions and prevent the deterioration of heritage. Furthermore, advisory members were included to insure the representation of the different cultures and regions in the world. When the cultural and natural heritage cases are finally defined and nominated, they are about to enter on the World Heritage List. However, the true task is after, when the owners and the Site Managers have to overcome the obstacles and conserve the property and the values that are represented by it (https://whc.unesco.org).

Together with the World Heritage Convention there are also other existing different other conventions, declarations and separate decrees and regulations from each country. All of them protect the cultural and natural heritage in a day-to-day manner preserving the past for the future.

3.3. Protection policy for architectural heritage

Mankind has formed theories and practices through time that aim towards the protection of cultural heritage among rules and regulations of spatial planning. The latter was formed in order to concede culture as a factor for development. However, over the last few years, the ecological issues are getting even more concerning and people are trying to deal with the challenges in contemporary cities by giving emphasis on urban heritage management within the frame of sustainable development (A.K. Sofia , ICOMOS, Korea, 2016). According to the conclusion of the 17th General Assembly Scientific Symposium in Paris (2011), "Heritage should be considered, not only for its protection and preservation and for the propagation of its values, but mostly for societies' cultural, social and financial development". Thus, the aims, methodologies and means to preserve urban heritage should correspond to the latest approaches of the concept of protection and sustainable development (CIOMOC-CIVVIH 1987,2011).

3.3.1. Declarations & International Conventions

In the mid-19th century, the preservation of the architectural heritage is manifested in Europe under the influence of the romance movement. In addition, the first theories are developed on the most appropriate way of intervening on the monuments to develop their rescue plans. Since then, a multitude of declarations and international conventions have been formulated and ratified by a large number of countries and by Greece. These include:

1. The Charter of Athens (1931)

The Charter of Athens was formed and adopted by the first international congress for architects and technicians of historic monuments in Athens, Greece, in 1931. The "Carta del Restauro", as it is called, contains seven resolutions that had to be followed by the members. More specifically, it was proposed to establish global organizations for restoration on operational and advisory sectors, since there were variants between recognising public law and the rights of individuals. Therefore, while approving the general path of these measures, the conference is of opinion that they should be in keeping with regional circumstances and with the trend of public opinion, so that the least possible opposition may be encountered, due allowance being made for the sacrifices which the owners of property may be called upon to make in the general interest. In addition, proposed restoration projects are to be subjected to knowledgeable criticism to prevent mistakes which will cause loss of character and historical values to the structures and this includes also the use of modern materials while restorating ancient monuments. Elaborating on the latter, all the resources at the disposal of modern techniques, like the reinforced concrete, are approved and should be camouflaged whenever possible in order that the character of the restored monument to be preserved. Last but not least, the Conference convinced that the best assurance in the matter of preservation of monuments and works of art originates from the respect and attachment of the peoples themselves, considering that these feelings can very largely be promoted by appropriate action on the part of public authorities (INTERNATIONAL CHARTER FOR THE CONSERVATION AND RESTORATION OF MONUMENTS AND SITES (THE VENICE CHARTER 1964), n.d.).

2. The Charter of Venice (1964)

After the Second World War the need for restoration of European cities created a wave of awareness among citizens for the rescue of authentic samples of structured cultural heritage, tradition and folk architecture. This need was expressed through the Charter of Venice signed by 17 states in 1964. The text includes both the conclusions of the second conference of architects and technicians, which took place after the Italian initiative in Venice from 15 to 31 May 1964 (INTERNATIONAL CHARTER FOR THE CONSERVATION AND RESTORATION OF MONUMENTS AND SITES (THE VENICE CHARTER 1964), n.d.). The Venice Charter formed critical principles for heritage conservation such as preserving the original setting for a monument, respecting the string contributions of all periods of a monument's history, replacing missing parts in a way that integrates harmoniously but remains distinguishable from the original fabric, employing a wide range of expert techniques, respecting archaeology, introducing interpretation and rigorously documenting the works undertaken. Also, of significant importance, the Venice Charter visualized that "each country being responsible for applying the plan within the framework of its own culture and traditions" (Preamble, Venice Charter, 1964). Based on Bronwyn H., the Venice Charter remains the most influential guideline internationally and is respected by heritage professionals for its brief but profound guidelines for looking after monuments and sites (Hanna, 2015). Among the findings was the notion that the preservation of monuments and far surroundings "Excluding any addition, any demolition, and any change that could alter the relationships of volumes and colors", and the separation of the ornamental elements of the monument only as an inevitable solution.

3. International Convention for the Protection of the World Cultural and Natural Heritage (Paris, 1972)

This Convention was being drawn up at the United Nations General Conference on Education, Science and Training, held in Paris in 1972 and ratified by the Greek Parliament in 1981 by Law No.1126 / 10-02-1981 (UNESCO General Conference Paris, 1972). In this article, Member States were invited to identify their cultural heritage and to undertake specific commitments and policies to preserve it. Moreover, particular reference was made to the information and education of citizens in order to respect the cultural heritage.

4. The Amsterdam Declaration (1975)

1975 in Europe was a year of architectural heritage with events in all the member countries of the Council of Europe, with the Amsterdam conference being the leader. The purpose of the conference was to take into account the results of the mobilization on the rescue of the architectural heritage. Its main slogan was "A Future for Your Past". The outcome of the conference was the Amsterdam Declaration that addresses the problems of the common European heritage, which is also a cultural heritage of the whole of mankind (Amsterdam declaration, 1975, ICOMOS). This text introduced for the first time the principles of integrated conservation, which should be a major subject of general planning and be included in the arrangements for regulatory and urban planning. It also entrusted the responsibility in the local authorities, which should have specific responsibilities, for the revitalization of the monuments and historical ensembles, in order to give them some use or function and their organic integration into the surrounding environment. Lifetime yields within urban planning were also their best preservation. Lastly, it recommended local authorities to introduce financial aid and tax exemptions for owners of buildings of particular architectural significance so that they can be maintained.

5. The Burra Charter (1979)

The Burra Charter for the Conservation of Places of Cultural Significance is a short statement of heritage principles which was conducted in ICOMOS Australia in 1979 and affected the cultural heritage management nationally and internationally. It started as a research project entitled " An oral history of the writing of the Burra Charter ", which addressed the question of how and why Australians developed this innovative approach to heritage management. Even though, the Burra Charter is the adaptation of the Venice Charter, whereas the latter speaks for the preservation and restoration of monuments, the Burra Charter talks about the conservation of the cultural significance of a place, giving emphasis to the significance that humans attribute to material culture (West S., 2010). Thus, this Charter is not only applicable to buildings, but also to city landmarks, parks, historic and archaeological sites, and suburban and regional places across Australia. Before any decisions about the future of a place were to be made, it needed to be understood along five specific lines of cultural heritage significance : aesthetic, historical, social, scientific and, later, spiritual () (/www.getty.edu/conservation/). Even though the Burra Charter is a product of the 1970s, it is still evolving by being reviewed for more explicit changes over time in order to address new challenges, like climate change and natural environment, in order for the heritage to be responsive in the future (Lesh J. 2019) ().

6. Granada Convention (1985)

The Council of Europe drafts the 1985 Granada Convention ratified by the Greek Parliament by Law 2039 / 13-04-1992 (Governmental Law 2540/2002, 1652/2009, 2338/2009, 2339/2009). This Convention, in addition to the principles of Integrated Protection Policy, specified the legal safeguards to be applied by the Contracting States and sanctions for any violations. More specifically, it is necessary to protect the architectural heritage as well as to ensure the integration of its protected elements into the social and economic life and to harmonize them as far as possible with the urban fabric of the site. Destruction of data that is of particular importance for its preservation is not allowed, as does any intervention involving the alteration of the urban fabric or the removal of the physiognomy or the disruption of their homogeneity. The Contracting States undertake to adopt positive measures intent to improve the quality of the environment in immovable monuments and to refrain from any action directly or indirectly damaging the monument or architectural ensemble or the surrounding area.

The above conventions express the European policy (WHC, https://whc.unesco.org) for the preservation and management of the Real Cultural and Natural Heritage and deal with the processes of preservation and incorporation of a heritage created in other times and " must pass on to future generations in its original state ".

7. The Nara Document on Authenticity (1994)

The Nara Document on Authenticity, as an extension of the Venice Charter, addresses "the need for a wider understanding of cultural variety and cultural heritage as it relates to the conservation, in order to evaluate the value and authenticity of cultural property more objectively" () (/www.getty.edu/conservation/). The document addresses the importance of cultural and heritage diversity through the different cultures and minorities, and how they should be preserved in a globalized world. It demands respect of all forms of heritage kinds, despite the extensiveness of them, and insists on the conservation of the heritage in all forms. In addition, it underlines the values of authenticity which are different form culture to culture, or even within the same culture, and heritage concepts should be judged only within the cultural contexts to which they belong. Last but not least, it is cleared that each cultural context is unique, because its evolution was based upon different internal and external factors, and they constitute an essential aspect of human development (ICOMOS : THE NARA DOCUMENT ON AUTHENTICITY ,1994).

3.3.2. Protection policies for architectural heritage in Greece

Greece, as a member of the European Community, had to co-ordinate in the spirit of these European Conventions. The domestic legal framework, in addition to the laws that validate the above conventions, also includes architectural heritage protection laws, the most recent of which are in line with European checks and are given below:

1. Law 1469/50 "Protection of special category buildings and works of art after 1830"

The special state of protection is regulated for works, buildings or monuments dated after 1830. At the same time, the designation process, which consists of a ministerial act with the agreement of a special committee published in the Government Gazette, is mentioned.

2. Article 24 of the 1975 Constitution

The Article 24 of the 1975 Constitution refers to the protection of the cultural and natural environment. Specifically, points out that it is an obligation of the state to create suitable conditions for preserving the cultural heritage. It authorizes the common legislator to define the necessary restrictive measures to protect it, as well as the manner and type for reimbursement of the owners. In particular, the Constitutional Court, in interpreting the article of the Constitution, emphasizes that the protection of this heritage, which consists of keeping the memorials and the surrounding area intact, presupposes the possibility of imposing both the necessary measures and restrictions on property, as well as the obligation of owners of monuments and other cultural heritage elements to take the necessary steps to preserve these elements unchanged but also to restore them in their original form in the event of their being worn by time or by human interventions or by any other incidents (Governmental Law 1413/2003).

3. Law 360/1976 :"Regarding town and country planning"

The Law 360/1976 defines for the first time the content of the natural and cultural environment, extending both the subject and the possibilities of protection. In order to protect them, it is possible to impose conditions and restrictions on functions and activities and the use of space and to impose measures for their rehabilitation and improvement (Governmental Law 360/1976).

4. Law 3028/2002 :"On the Protection of Antiquities and the Cultural Heritage in general"

The Law 3028/2002 is an extensive and systematic piece of legislation that includes all the terms set by international conventions and signed by Greece. This law regulates issues that until then have been insufficiently regulated to a minimum and is trying to equip the country with important mechanisms of protection.

5. GBR (General Building Regulation)

The protection of architectural heritage has been included in the GBR since 1973. There are suggested ways in order to ,initially, prevent the material destruction of the building, and ,then, to revitalize it and to integrate it into the immediate and wider space that includes it. Later, in the new GBR (GBR 85, L. 1577 / 85, article 4), is provided the procedure for characterization of settlements or their parts as traditional and buildings as preservatives is provided. In this edition of the GBR, this issue is addressed in Article 3 (Governmental Law 2831/2000)

6. Law 1377/83 "Extension of urban plans, residential development and related regulations"

Conditions are set, and procedures are established for the approval and development of specific studies in traditional settlements and protection zones. The provisions of Article 32 of the Law stipulates in particular that the owners or administrators of the buildings designated as "preserved" must retain the architectural, artistic and static elements of such buildings and, in any event of their destruction, reconstruct them in accordance with the instructions of the competent committee for exercising architectural control, even if the destruction is due to "greater violence ".

7. Presidential Decree 28/4 / '88 "On the conservation, repair or restoration of architectural and static elements of listed buildings"

It was issued in implementation of the provisions of the Constitution and Law 1377/83. It provides for severe sanctions for arbitrary disasters, alterations, demolitions of preserved and traditional buildings in traditional settlements.

In addition to the laws, Greece is seeking to preserve its cultural heritage, and it has also been well-suited to spatial and town planning. Since the early 1970s, the Member States of the European Community, including Greece, have agreed that "In order to achieve a more reasonable management of resources and thus to improve the environment, the states must follow a comprehensive and organized approach to the development designing them to ensure that development is in accordance with the need to protect and improve the environment for the benefit of the population" (Declaration of the United Nations Conference on the Human Environment, Stockholm 1972, principle 13). This coordination can only be achieved through a policy of long-term and integrated development planning.

To sum up, the legislative framework of Greek Constitution includes regulations about heritage protection and their integration into the urban environment, which ,all in all, follow the international Declarations that Greece has signed. However, the regulations are not cohesive, and, in many cases, there is just reference for protection but no specific guidelines, for example what is the valuable in each case, the materials and/or the style itself. In addition, and based on the information found for the case study in Greece, that is going to be studied and analyzed in further chapters, buildings are considered as "listed" and "work of art" based on Decrees which were made, initially, for older buildings or cases. This leads to the fact that many different cases are being referred as protected based on one heritage case, usually different each time, that share the same style.

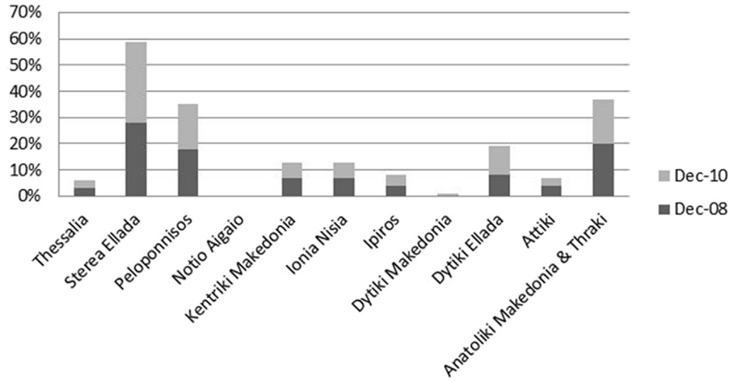


Figure (6) : Allocation of renewable energy sources installed capacity in the administrative Prefectures of Greece, Dec.2010 and 2008 (Manolopoulos, Kitsopoulos, Kaldellis, & Bitzenis,

3.4. Strategic energy interventions

3.4.1. General strategic energy interventions in Greece

Generally, the energy-saving interventions have better performance in old, energy-intensive buildings. Two basic factors that influence the energy performance of a building are the active systems and the thermal transmittance of the building envelope. In Greece, 50 percent of the buildings were built before 1980 (Hellenic Statistical Authority, https://www.statistics.gr). The energy efficiency of these buildings is very poor, due to the fact that they lack of insulation, aluminum frames and double-glazed windows, and they have, usually, concrete structure with masonry walls, and thus they have a great potential for energy savings through energy efficiency measures.

However, regulatory authorities have stated that there are reservations in order to accomplish successful energy-producing scenarios, since there is a slow pace in the development of renewable energy sources, mostly because of severe problems that the projects are facing at the implementation phase, such as grid problems, complicated administrative procedures and, to some extent, low amount of social acceptance from local communities (Manolopoulos et al., 2016) (Figure 6).

3.4.2. Solar energy in heritage context: Guidelines from the Flemish Government.

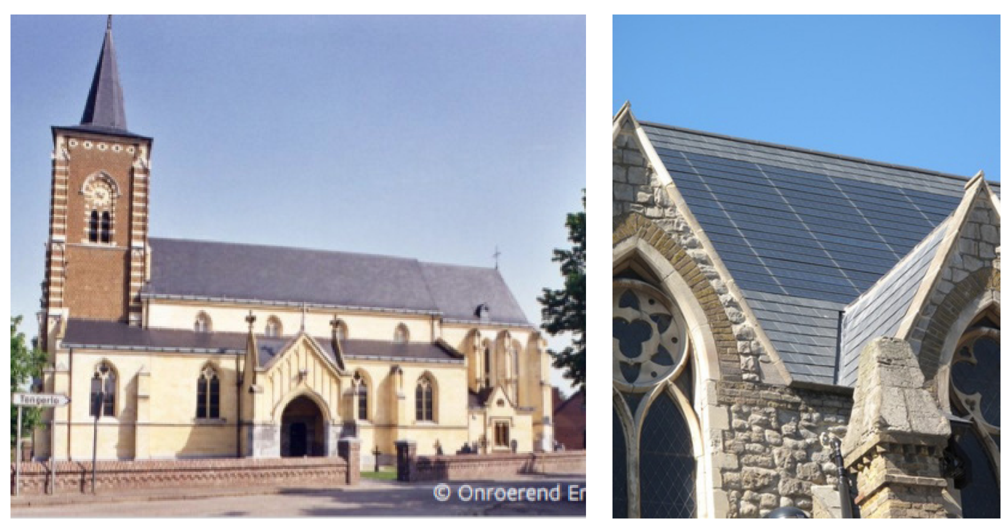
With a view towards realizing the climate targets, the Flemish government is focusing on the production of renewable energy. In the VISION 2050, the long-term strategy for Flanders, "ensuring an energy transition" is presented as a high priority. In the context of this, the Flemish Energy Agency created the so-called Solar Map with which every citizen can check how suitable their roof is for placing solar panels or a solar water heater. Based on this Solar Map, the suitability depends on the slope and orientation of the roof and additional factors, such as the fall of nearby higher buildings and trees. In addition, an assessment framework was designed to provide objective guidelines for location-specific circumstances for acceptable solar installation. The purpose of this is to provide transparency in the process of solar application in heritage buildings and justification for the assessment and decision making (Rob Zakee, 2019).

The Flemish framework, which is proposed without a binding character, consists of different steps for assessing the application of solar-generating system in a heritage concept and the corresponding criteria which have to be followed.

The process starts by classifying the heritage value of the building and the building's site, in order to identify the depth of detailing in the materialization and the characteristics of where the solar energy is to be generated. The next steps are the investigation of the physical state of the building, whether the condition allows the installation of a solar energy system, and the estimation of experience value of the specific part of the heritage site. In the flow of the process, as it continues, minimizing the visual impact of the application with the architecture and the environment is a milestone for the end result. Finally, extra points of attention are proposed to be considered, such as fire safety and finishing of pipes and cables, in order to complete the application(Rob Zakee, 2019).

The justification of the heritage value is always the starting point within a protected environment. But every case is different. Thus, based to the Immovable Heritage Decree in 2013, the Flemish Government has conducted a table which the risk scale is defined based on each heritage value:

High risk of damage by winning solar energy	Risk depends on the specific motivation	Without the risk of damage by winning solar energy
Architectural value	Archaeological value	Cultural value
Artistic value	Industrial-archaeological value	Social value
Aesthetic value	Unrban planning value	Folklore value
Historical value	Technical value	
Spatial-structuring value	Scientific value	
	Common interest	
	National importance	



Figures (7): Parochic Church St. Trudo in Bree (left), St. Silas Church in London (right)

The above heritage values give a general appreciation of the site. It has to be underlined that there may be additional values that are site-specific and certain regulations have to be followed. Within a protected environment, a distinction is made between elements and features that are more valuable and those that have lesser heritage value. Generally, the typology, style and culture of a site are elements that could determine whether a site has a heritage value or not. It is therefore of great importance that the readability of a site or building is preserved when solar energy is gained. For example, the façade rhythm should not be affected, the exterior should remain clearly legible, and ornamental elements should remain visible.

The integration level is another focus point in the Flemish context. The advantage of built-in installations such as power-producing slates or glass is that they are integrated in the original plane of the roof, making them less noticeable. In addition, technological developments aim to produce current-producing building materials that visually resemble traditional materials in the aspects of gloss, structure and colour. For example, a roof can be valuable because of the use of a special or vulnerable material, a special or decorative laying pattern, a special roof shape, or valuable detailing. In these cases, based on the Flemish Decree, the heritage value of the roof should not be damaged by the installation of a solar energy application. If the building material, on the other hand, has less heritage merit, solar energy components could be placed above the traditional building material or replacing the material completely (if is meant to be replaced)(Rob Zakee, 2019).

Furthermore, the Flemish guidelines consider as important the experience value, which is the value of the part of the building that is visible from important street views. Due to the non-matching color, solar panels are considered to have a negative effect on the experience value of a site. However, there are systems and products that do not have these drawbacks, like fully integrated solar systems in roof or special solar panels that fit the different requirements.

More specifically, for the roof installation, it is proposed that the application should be positioned as low as possible and with the same slope as the roof surface, in a continuous group in a rectangle or square, and in alignment with other roof elements, like dormer windows or skylights. For the façade placement, grouping and aligning the elements are also vital for the application, as in the roof. In addition, all parts should be placed in the same position, be of the same type and size, and parallel to the façade.

To sum up, the Flemish Solar Map is following the above guidelines in order to install solar panels in heritage buildings. However, some examples which are presented to follow this flow, appear not to be suitable for solar installation. The usual reason behind this decision is the visibility of the panels from important street views and the effect that would have in the experience value. On the other hand, similar cases in other countries, like England, did not affected by the visibility of the panels, and as attested, from the collected data, the application decision is following the same steps as the Flemish Solar Map. An example is the application of solar panels in a church. According to the Flemish guidelines, no solar panels could be placed on the roof of the Parochic Church St. Trudo in Bree, because of the position of the roof and the importance to the experience value. On the other land, on the roof of St. Silas Church in London, 362 grey solar panels have been placed, making it the first solar application on heritage in the UK. To be noted, that the panels used were specially designed to match the color of the slate following discussions with the architect and planning authority (Figure 7).

3.4.3. Solar energy in heritage context: Guidelines from the Dutch Government.

In the Netherlands, the Cultural Heritage Agency wishes to investigate possibilities for a collective approach to sun projects on heritage buildings, and especially on national monuments and protected city and village image. Based on the energy road map, Netherlands are committed to achieving a CO_2 reduction of 40 percent by 2030 and 60 percent by 2040, as it is an average over the entire stock of monuments. In addition to that, the country consists of 118.000 monuments in total, of which 62.000 are national monuments (https://www.erfgoedmonitor.nl/). Comparing with the total built stock, the number of monuments is only about 0.1 percent of the total. However, according to the report of Cultural Heritage Agency, placing solar panels on the roofs of monuments influences the quality of the monument itself and gives the opportunity to pass to the future generations in a responsible way. That is what makes the solar application in heritage buildings so important.

More and more cities in the Netherlands want to include the heritage buildings into the energy transition initiatives. According to Sandra Hovens, monument care consultant at the municipality of Amersfoort, heritage buildings owners should contribute to sustainability national objectives, by participating in energy saving and producing. In June 2019, they declared that they are currently investigating new policies to widen the barriers for photovoltaic panel application in heritage buildings. In addition, according to Hovens, the municipality is searching for alternatives to solar panels, such as a solar collector system for heat generation under the roof tiles, which can optimally be integrated into historical roofs providing hot tap water and can be also combined with heat-cold storage systems.

The project “Collective Sun Projects” (Collectieve Zonprojecten) was formed via local energy cooperatives, who are already practicing renewable projects, and a postcode scheme, the SDE. This project aims to observe the city on a local level, which can justify the cultural and historic value of monuments and protective sights, and what is more, creates financial potential of residents of national monuments and boosts the generation of clean energy (Broström & Svahnström, 2019). In addition, it aims to arrive in a point that can be used nationally. That said, the owner can access a platform that gives information about the solar potential of the monument. Until now only few roofs are suitable for the installation of solar panels due to strict municipal guidelines for cultural city-view protection. However, the government suggests that the alternatives should be presented to the citizens in order to be accepted. Such an example is the installation of solar roof tiles that could also imitate the existing tiles, instead of the classic solar panels.

An example of solar energy application in a heritage context, is the energy-neutral castle village, Haarzuilens, in the Netherlands. The village is historically linked to the nearby De Haar castle and is an original example of local brick craftwork, thatched roofs, old Dutch roof tiles and red-white doors and shutters that are aligned with the castle. Based on the “green” energy belief of the residents, the Haarse Zon energy cooperative offers the solution of the collective solar panel installation on roofs on the outskirts of the village. According to Paul Rozmus, chairman of Haarse Zon, the village consists of municipal and national monuments and their roofs are too small for solar panels to be laid in a way that the townscape is preserved.

Moreover, the Delft city council wants more solar panels in the protected cityscape. The first steps were confirmed on May 2012, when the application of solar panels was made possible, but only out of sight from the public space. According to Edwin van Gastel, owners who wanted to install solar panels on their roofs should follow a number of criteria to test whether an environmental permit is required for the application. In addition, the solar panels may be hardly visible from the public space and are fitted into the existing architecture of the building. In most cases, also, panels should be placed on roof surface at least 4 meters from the front façade. With that said, based on the municipal criteria, large monuments such as the Nieuwe Kerk are excluded from the scheme (https://www.hieropgewekt.nl/).

The directions, thoughts, from the government, despite the demand for including the heritage buildings into the energy transition scheme, do not consist of clear spatial framework and guides. Thus, it is a matter of "learning by doing" and is therefore advisable to set up a number of pilot programs at municipalities and central government with several advices for building owners.

3.4.4. Solar energy in heritage context: Guidelines from the British Government.

The British Government is, also, trying to involve heritage culture into energy transition. As the previous countries recommend, so the guidelines from the British government are following the same pattern. That is the potential visual or physical impact on the building's historic fabric, the consent that should be given form local authorities, the technical risks associated with the installment, and the payback period (Historic England, 2018).

However, the guidelines contain a special segment for places of worship. That is about the needed permission from the qualified authorities and the measures before deciding the application, such as consulting with the local community. Places of worship with large south-facing roof slopes present opportunities to generate energy through solar electric panels or solar "slates". Such roofs are often highly visible and therefore contribute to the character of the building in its setting. Minimizing visual impact is desirable from the local authorities, but often difficult and will depend upon the form of the roof on the situation of the building. Even though solar slates are designed to have a similar appearance to natural slates, the difference is usually still detectable to the naked eye and thus has a visual impact. The life-expectancy of solar slates is much shorter that a natural slate roof so the cost of more frequent roof repairs should be taken into account. Solar slates may be acceptable where the roofing material is not part of the building's historic integrity and the existing slates are in need of replacement (Historic England, 2018).

In addition to that, special attention is given to the reversibility and the physical impact of the installation. According to the guidelines, a photovoltaic installation and its associated equipment can have a life exceeding 25 years, so a building could have more than one system installed over its life. Damage to the building fabric can be minimized by carefully planning how the array is installed, maintained, and removed at the end of its useful life. Moreover, however careful the installer, during the installation it is possible for tiles and slates to get broken to it is advisable, from the Heritage England, to have replacements available. Specifically, for roofs with stone or old handmade tiles, replacements can be expensive and very difficult to find. It is therefore recommended to investigate what type of roof covering there is and how to get replacements before undertaking any work and whether installing panels on the roof is the right solution (Historic England, 2018).

Generally, it is not recommended, by the British guidelines, adding to a building's appearance solar panels or other equipment fixed to any of its main elevations i.e. the face or faces seen from the principle viewpoint, towards which it is mainly viewed. Thus buildings with main elevations aligned in the direction of optimal solar radiation

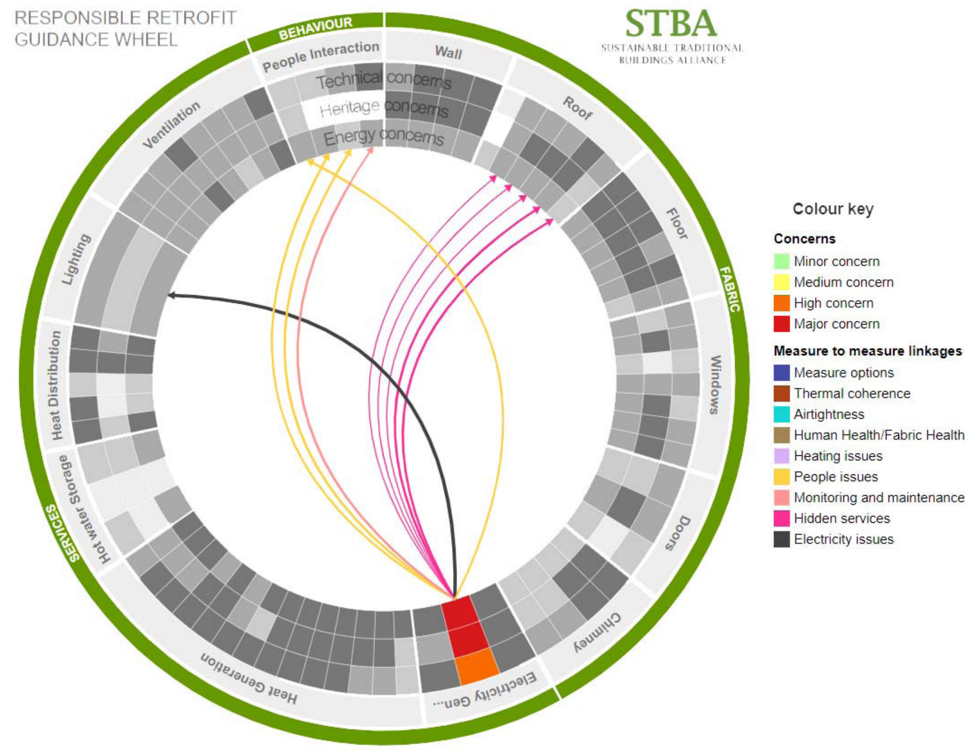
may present special installation issues with regards to visual impact (English Heritage,2010).

Furthermore, special approval should be taken from Natural England at an early stage when planning an installation with known wildlife interest or in areas known to be used by protected wildlife. Bats and birds use buildings for roosting and nesting, and especially bats can roost under very small spaces in roof coverings or inside roof spaces. When planning an installation it is needed to assess whether they are nesting or roosting in or on the roof, as all bats and some birds are legally protected. If they are using the building, the installation should happen when they are not present. Subsequent maintenance will also need to avoid times when it is a roost is being used, as bats tend to re-occupy the same every year (English Heritage,2010).

STBA

As a mean to the energy transition in the UK, the Sustainable Traditional Buildings Alliance (STBA) has been established. This is a collaboration of non profit organizations that aims to promote and deliver a more sustainable traditional built environment in England. The five keys based on the organization are: the health of the occupant, the health and durability of the building fabric, the energy consumption attributed to the building, the impact on British communities and culture, and the on the natural environment.

That said, the concept behind the Guidance Wheel developed from the ideas and



Figures (8): Guidance Wheel focucing on Photovoltaic application on heritage buildings (http://responsible-retrofit.org/)

work for a Triage system by William Bordass Associates that were funded by English Heritage in 2010. The purpose of it is to explore potential retrofit measures in more detail, with a specific building (or set of buildings) in mind. The give information considers the building's context including heritage value, state of repair, exposure and the building users.

In the examination of potential measures, the Wheel identifies different benefits and concerns regarding the three categories of energy (and to some extent carbon), heritage (including community issues) and technical (meaning all non-energy-based material consequences including the health of fabric and occupants).

Benefits are made clear in text underneath each measure and concerns are categorized as four levels of risk indicated by color (red, orange, yellow and green). The concerns are explained, and they are linked to relevant references so that further understanding of the issue can be researched. The Wheel also indicates useful actions before, during and after retrofit to reduce the risk of various measures. It also indicates important relationships between measures and thus provides a holistic, systemic approach to the retrofit design, application and use, thereby reducing the risk and increasing benefits as well as understanding (STBA, http://responsible-retrofit.org/)

In the "Electricity Generation" tab of the Guidance Wheel, by selecting the photovoltaic installation a diagram is produced directly **(Figure 8).** First of all, and based on the color keys, there are major concerns about heritage and energy, and high technical concerns. Regarding the roof, the reason for concern is about hidden services and pipes and is recommended to ensure pipe-cable-duct installation and to seal around penetrations of air tightness layer. Regarding the lighting, the reason for concern is about the electricity issues and upgrading the lighting system. Thus, it is recommended reducing the lighting use, installing energy efficient fittings and then considering renewable energy sources. Extra attention is given to the "People Interaction" tab. The reasons for concern is about the maintenance of the installation, and the people acceptance. For the latter, it is recommended to motivate and engage users, to promote simplicity of using the installation, and to provide them with clear information on reasons for measures and on positive consequences. All these are aiming to improve understanding and avoid frustration.

All in all, the Wheel appears to be an excellent tool for retrofitting heritage buildings and gives all the possible solutions and concerns. That tool is suitable for a start in every case study, as it covers all possible concerns, but also during the process of the decision making in order to check if every possible concern has been counted.

3.5. Conclusions

To sum up, it is clear that all countries appear to have the same concerns, and thus guidelines, regarding the photovoltaic application on heritage buildings. Nevertheless, each country has different tools in order to cover all aspects, there are some differences. The Flemish government is concerned more about the evaluation of heritage building and the physical state, reassuring the possibility before any decision being made. The Dutch government is concerned more about the protection of the city-view, and thus the four-meter-rule for the cultural city centers. Last but not least, the British Government is concerning more about the harm of the installation to the heritage building and how possible is the reversibility of the application.

However, since all these countries are parts of the European Union and have signed the UNESCO agreements and international declarations, specific guidelines should be formed which would be implemented internationally but altered by each country's traditions and culture, likewise of what happened with all international agreements. With this way, countries which do not have a solar-heritage framework yet, would join the movement and expanding their legislation.

4. Solar Design: Photovoltaic Technology

Figure (9): Photovoltaic modules on roof (http://slapcoffee.com/)

4.1. Introduction

Solar energy's active use in existing buildings has only received the public's wider attention quite recently, even though it exists from 1954. While incorporating the solar plant into new buildings without technical or architectural problems is feasible, from an architectural aspect, the complementary appliance to buildings that already exist, often leads to unsatisfactory results (Figure 9). Thus, innovative approaches should be found, in order to match elements of old buildings and monuments such as their materials and decorative features, their scale and color, with modern technological elements.

In industrialized countries, on average about half of total energy consumption is allocated to the energy supply of buildings, i.e. heating, cooling and ventilation, and general energy supply (Energy roadmap 2050, 2011). The energy required for this is still derived from non-renewable fossil fuels and the conversion process entails the release of emissions that can damage the environment severely.

Due to the fact that the availability of fossil energy sources is limited and the upcoming, or even already occurring, changes of the climate, the worldwide rational application and efficient use of energy have become primary social and political goals (Energy roadmap 2050, 2011). Solar energy should also be a primary concern in creating a built environment as a responsible approach to the environment and the use of renewable energy sources.

The design of buildings in each case, should thus aim at making the least possible use of energy. In new buildings this can be achieved with appropriate orientation, such as solar energy's passive use and choice of materials. In the case of heritage buildings though, energy consumption can be highly reduced by insulating the building envelope, installing windows with better insulation characteristics, exchanging heating systems, etc. The remaining energy demand has to be transformed from active systems using environmental energy.

For instance, in Germany, there are about 70 percent of buildings over 25 years old and together they consume 70 percent of electricity and 95 percent of heat in all buildings, approximately (Hermannsdörfer & Rüb, 2005). Maintenance and renovation measures in existing buildings will present the most common tasks for designers, architects and the construction industry in the following years, as the overwhelming majority of building activities are already taking place in this area (Heritage England, 2018). Therefore, renovation of old buildings is more decisive than the activities on new buildings to determine the extent to which energy consumption in buildings can be reduced and how conversion to renewable energy can be achieved (Hermannsdörfer & Rüb, 2005). Both are equally important: The use of renewable energy sources is not a substitute, but rather a modern supplement to measures aimed at saving energy.

Nevertheless, the use of renewable energy sources is now seen as the main objective of new buildings. This also comprises solar architecture, as solar thermal and photovoltaic installations can be integrated notably well, if designed together with the building as a whole from scratch.

4.2. Technical Part of Photovoltaic Technology

Explaining the technical part of the photovoltaic technology is very important in order to understand the difference between the different modules that exists on the market nowadays. Different technologies provide different energy efficiencies, different energy production, and also different final appearance, as it is going to be explained thoroughly in this chapter. The above characteristics are important to the application of photovoltaic modules in buildings generally, and in heritage buildings, mostly, from the appearance point of view.

4.2.1. Solar Energy

Solar radiation consists of electromagnetic waves of a broad spectral distribution. The largest part with approx. 50 percent comprises visible radiation of wavelengths between 380 and 789 nm (nanometers) (blue-red). The remaining part consists of infrared radiation and ultraviolet radiation which are not visible for human eyes. For an understanding of photovoltaics, a consideration of the quantum picture is appropriate. According to this, light consists of quanta of different energies, also called photons. The incident part of the energy, which is not absorbed by dust, clouds and ozone, is called global radiation. It consists of direct and diffuse (reflected) radiation. The incident energy depends on the degree of cloudiness, the altitude of the location and the position of the sun mainly depending on season, daytime and geographic latitude. Only at the equator is relatively constant.

On a clear day the sun radiates a maximum of 1 kW (kilowatt) onto a rectangular area of 1 m2 oriented perpendicular to the incoming radiation. In northern Europe this powers adds on average to an annual energy of 800 to 1000 kWh (kilowatt hours), in southern Europe this value is higher, namely about 1300 to 1500 kWh per year.

4.2.2. Solar Technology

Solar technology takes advantage of solar energy. There are two kinds of so-called power generators: thermal and photovoltaic ones. They vary not only in the principle of operation but also in their appearance. From the one hand, a solar thermal generator, a collector, converts solar radiation into thermal energy, which is stored and transported by and transported by water or other liquids and is used for room heating or provision of hot water. On the other hand, a photovoltaic generator, a solar module, converts the radiation energy of the sun directly into electric energy.

4.2.3. Photovoltaic Effect

The term photovoltaic is derived from the Greek word for light (fos) and the unit of electric voltage (volt). The photovoltaic effect takes place by light-induced generation and spatial separation of positively and negatively charged carriers in a semiconductor. In semiconductors negatively charged electrons or their positively charged counterparts (so-called defect electrons or "holes") can be liberated by introducing different foreign atoms (doping) into the lattice ("n-doping", respectively "p-doping"). A contact between a p-doped and an n-doped semiconductor is called a p-n junction. This region maintains an electric field. If it is irradiated by light, photons are absorbed and generate additional free charge carriers, which are moved by the built-in electric field. Thus an electric current is created, which will flow as long as the light is shining. If the current is not conducted away, a voltage between the p- and n-regions is generated.

4.2.4. Solar Cells & Modules

Solar cells have been established since the end of the 1950s to provide electric power to spaceships and satellites and have since been steadily developed further. The core element of solar cells is, as described before, a p-n junction. For that reason, solar cells consist of two differently doped semiconductor layers. The following semiconductors are used today: mono- and polycrystalline silicon (Si), amorphous silicon (a-Si), cadmium-telluride (CdTe), or copper-indium-diselenide ($CuInSe_2$) also called CIS.

In the cases of CdTe and CIS, the active, positively doped CdTe and CIS films, respectively, are and covered by negatively doped cadmium-sulfide (CdS) films in order to obtain p-n junctions. Such diodes are called "heterodiodes" as different semiconductors are employed in one cell. Silicon solar cells consist only of (n- and p-doped) silicon.

As a rule, solar cells are made in the form of disks or films. The p-n junction is positioned parallel to the surface. By the absorption of incoming photons, charge carriers are liberated, which are moved by the built-in electric field of the p-n junction, forming an electric current. Metal contacts transport the current to the consumer. In order to enable light incident onto the surface to enter the semiconductor, the contacts on the light-facing side of the cell generally consist of narrow, comb-like conductor stripes or transparent conductive layers. At the back of the cells, where no light enters, a homogenous metal layer is deposited.

The semiconductor most widely employed for making solar cells is silicon. Three different techniques are used, leading to three different types of solar cells: monocrystalline, polycrystalline and amorphous.

In the case of monocrystalline cells (Figure10), broken, pre-cleaned silicon is molten and at 1400 C a cylindrical single crystal of 15 to 20 cm^2 diameter grows, starting with a small nucleus. This crystal is subsequently sawn into 0.2 to 0.3 mm thick discs ("wafers"). Out of these round wafers, typically squares of 10 to 15 cm length are cut. In some cases the more material-economic round wafers are used. To obtain polycrystalline (also called "multicrystalline") cells, silicon is molten in rectangular cubicles. Upon solidification, rectangular crystal blocks are obtained (and later also cut into wafers). Under these conditions generally crystallites of different sizes are forming the solid material. The p-n junctions are generated by in-diffusion of doping atoms (typically phosphorous) at 800 C. Monocrystalline silicon cells show a more homogeneous color than polycrystalline cells, which get a more varied appearance by the process of solidification (Figure 11).

Regarding the amorphous silicon cells as well as those of CdTe and CIS are produced

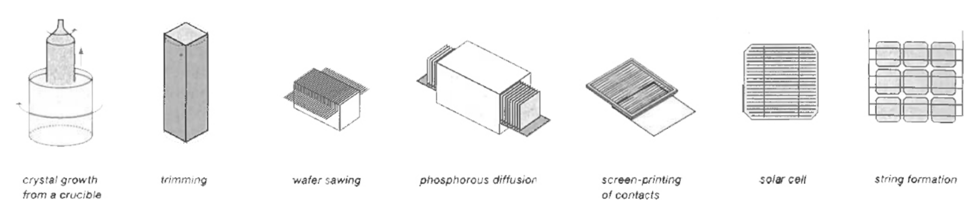


Figure (10): Stages in the production of monocrystalline (Si) module (Hermannsdörfer & Rüb, 2005).

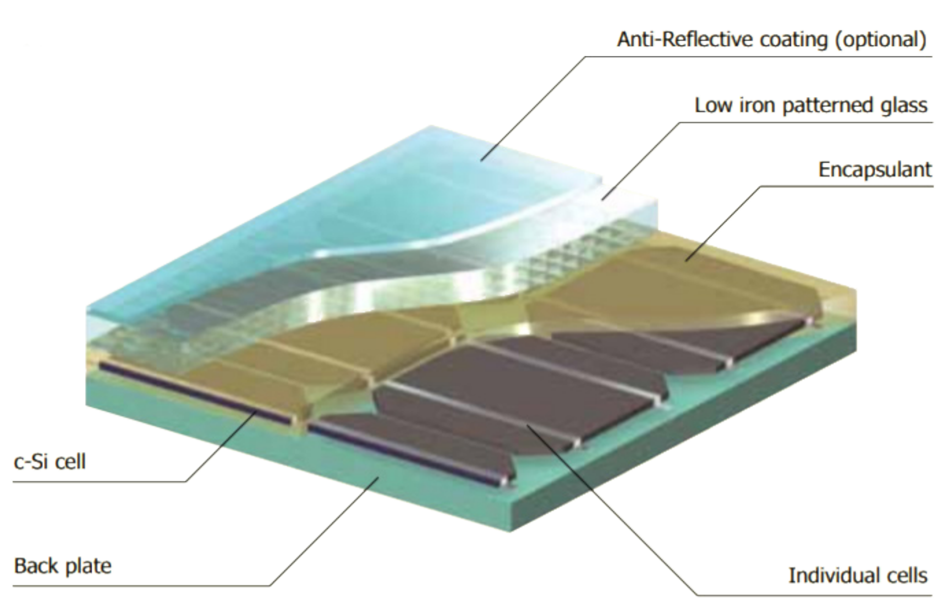


Figure (11): Crystalline Silicon Photovoltaic using a patterned surface, Generic Construction (https://www.pilkington.com)

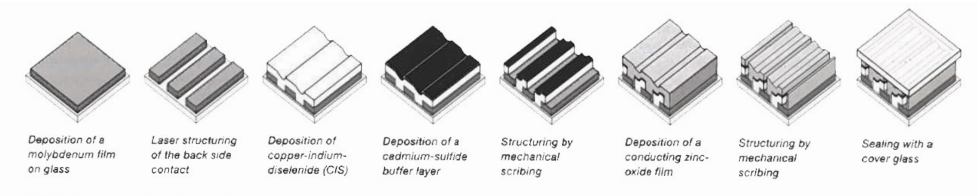


Figure (12): Stages in the production of a CIS-thin film module (Hermannsdörfer & Rüb, 2005).

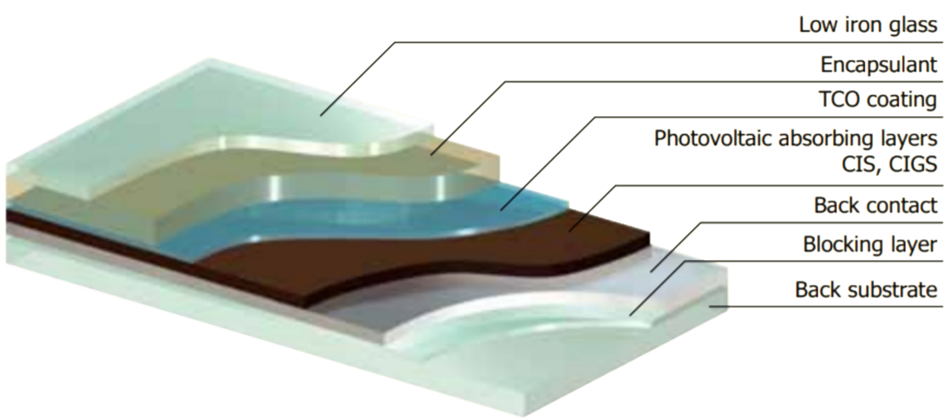


Figure (13): Generic Substrate Construction (https://www.pilkington.com)

by the deposition of thin films on a suitable carrier material (substrate) (Figure 12). On the front surface of the cells, the aforementioned grid of conductor stripes is deposited and, in addition, an antireflection layer. This antireflection layer, which is only a few hundred nm thick, deduces light deflection, like in photographic lenses, and thus enhances the efficiency of light utilization. This layer is adjusted via its thickness so that the reflection of light from the red spectral region (for which the cells shows highest sensitivity) is minimized. As the reflection of blue light is less reduced, the cells show the well-known blue-black appearance. By variation of the thickness of the antireflection coating different colors can be obtained, for example magenta or golden, causing, however, a lower light use(Figure 13).

The most common standard modules are based on crystalline silicon cells. Thin-film modules are a more recent development. In order to efficiently use a wider spectral range of light, experimental studies are underway, which use “tandem” or “stacked” cells, in which different semiconductor materials are positioned on top of each other, using different spectral parts of solar radiation.

Photovoltaic modules consist of electrically connected solar cells, which, in order to protect them from harmful environmental influences (mechanical wear, weather conditions, corrosion) are sealed between suitable materials, mostly glass, using transparent plastic sheets as “glue”. The minimal distance between cells in crystalline silicon modules is 2mm. Standard modules show cell separations of 2 to 5 mm. Thin-film modules, consisting of cells which are mostly 1cm wide, have barely visible interspaces of approximately 0.5mm (Hermannsdörfer & Rüb, 2005).

Silicon cells typically exhibit voltages between 0.5 and 0.8 V. As such low voltages are not desired for practical applications, higher voltages are obtained by a series of connected cells. Parallel connection leads to addition of currents of the cells at the same voltage, whereas series connection leads to addition of the voltages of the cells. Usually crystalline silicon modules are manufactured having 36, 72 or 144 cells at voltages of 20 to 70 V (Hermannsdörfer & Rüb, 2005).

Thin-film modules are made of new semiconductors, such as amorphous silicon, copper-indium-diselenide (CIS) or cadmium-telluride (CdTe) (Figure 14). In automated processes individual cell structures are deposited as films on top of each other and are connected serially and directly without visible contacts onto suitable substrates, such as glass. This leads to a significantly more homogeneous appearance than observed in crystalline modules. By appropriate structuring of different films shaping the cells, integrated connected modules are produced immediately, containing typically 100 serially connected cells. Thin-film technology leads directly to complete modules. Common module sizes are 60cm x 120cm, but the production of smaller or larger modules is also possible. Typically, the color appearance of thin-film modules is black, and in some cases dark green or dark brown.

The production process makes the difference between copper-indium-diselenide (CIS) and cadmium-telluride (CdTe) modules. For CdTe-modules the front glass, which is exposed to the sun, is the substrate, for example the carrier, onto which the films representing the cells are deposited and onto which the second (protective) glass is laminated later on. For CIS-modules the substrate glass, onto which the films are deposited, is later on turned away from the sun and the second glass, which is laminated into this first glass, is turned towards the sun. During the production process, maximum temperatures have to be achieved in order for quality materials to be produced. In the first case (CIS) the glass could heat up to 200o C in contrary with the second case (CdTe) that the glass could undergo the thermal heating up to 500o C. In order to achieve the best quality materials to both modules, it is possible to use a structure or colored glass to CdTe as substrate, but this may cause technical risks such as breakage. Fortunately, after the production of the CdTe module, a printed or colored glass sheet could be laminated onto the substrate glass, which now experiences a temperature of around 200o C, but that could lead to an increased module weight of 20 percent.

In order to protect the system of interconnected solar cells for their lifetime from environmental influences and guarantee their proper operation for a long time, the cells are joined with suitable materials (back and front) forming a compound system. In the case of crystalline cells, this is accomplished by resins or plastic sheets under pressure and at elevated temperatures. The covers can be glass, acrylic glass or foils. In the case of thin-film modules, glass or a heat resistant material, such as a metal

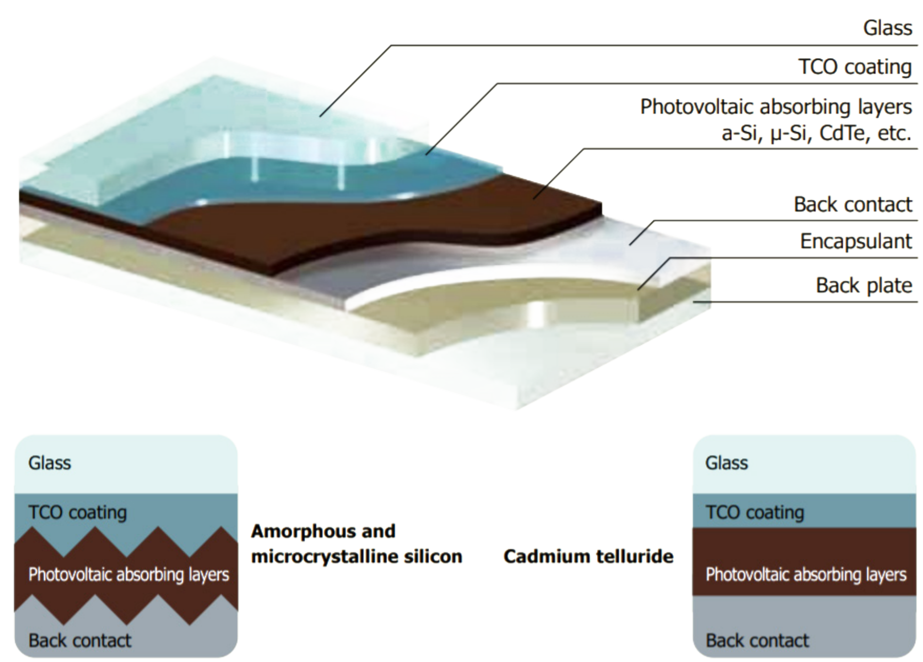


Figure (14): Thin Film Photovoltaics, Generic superstrate construction (a-Si, µ-Si, CdTe) (https://www.pilkington.com) sheet, are used for the back and glass or foils at the front. Whereas for CIS-modules highly transparent iron-poor white glass is used, for CdTe-modules a standard window pane glass (sodium-lime glass) is sufficient. The difference between layers is hermetically sealed with plastic.

A glass/glass module is de facto a compound or laminated glass, in which the included plastic sheet guarantees stability upon breakage. It can be therefore used directly in insulation or overhead glazing, which generally requires a multi-glass pane for thermal and safety reasons. Only laminated glass using PVB (poly-vinyl-butyral) has the basic permission for such use in overhead glazing. For modules using EVA (ethyl-vinyl acetate) a single permit is usually obtained from the authorities.

Standard modules are generally offered with frameless modules. A frame improves sealing of the module and also protects the edges from breakage but implies higher costs. The electrical connection is obtained via integrated contact boxes at the rear, special cables and water-protected plugs. For design and construction-related reasons, for example in facade installations, it is often recommendable to use frameless modules.

4.2.5. Photovoltaic Plants

There are two different types of photovoltaic facilities: Island systems or stand-alone systems, which are independent from the power grid and, in order to guarantee continuous power supply over the year at varying yields, require storage or backup systems. Suitable components are accumulators, respectively batteries or backup generators, respectively, including power conditioning systems, like charge-controllers for batteries.

The second type are grid-connected systems, which feed their power into the public utilities' grid and take power out of the grid, in order to compensate for output variations. These systems need a surveillance system for coupling to the grid, distribution systems and current counters for determining cost, respectively reimbursement.

Besides the aforementioned specific and differing components of both systems, the following elements are required in all types: inverters, switching systems, especially decoupling switches for service work, as the modules under solar irradiation always deliver a voltage, an automatic turn-off switch in the case of a fire, special cables (suited for dc electricity), suitable fuses and lightning protection.

Besides the modules, the inverter is the principal system component. It changes the direct current produced by the modules into an alternating current at 50Hz and 220V for direct use in standard appliances or to feed it into the grid. It has to be adapted to the installed power level. A central inverter is used under homogeneous irradiation of the total module area. De-central inverters can be added and are suitable if different parts of the module area are experiencing different irradiation profiles (e.g. by different orientations to the sun), or to allow addition of further moles, Inverters should be positioned in a cool, well ventilated place, as they emit 2 to 5 percent of the generator power as waste heat.

Regarding the layout of the plant, the size of an island system is determined by the average power demand, the time of usage and the peak demand. The plant should be designed so that it can guarantee supply even in times of maximum demand. Safety of supply can be improved by an energy management system, which switches on large consumers (like washing machine) only at times of high supply (around noon). Such energy management as well as use of economic consumers can significantly reduce the size of the plant. In the case of grid-connected systems, the size of a plant will more likely be determined by the available area and capital. The energy buffer is provided by the utility, which can use surplus energy from the photovoltaic plant to cover peak demand of other customers. Photovoltaic power is especially well suited for use in commercial entities, which have peak requirements synchronous with the power production and can shave-off demand on the utility at expensive peak times. In residential buildings peak demand occurs typically at times when the supply is lower (morning and evening) and at noon a surplus is generated. Under conditions of the present reimbursement law in Germany the total photovoltaic power is typically sold to the utility, which reimburses a higher amount than it charges. This makes an energy management system for the facility owner redundant.

4.3. Energy Yield & Orientation

The energy yield of a photovoltaic plant depends primarily on the geographic location, the irradiation duration and the incident angles of the solar radiation. It is determined as an annual yield in kWh/m^2.

To achieve a maximum yield the modules should be oriented at an optimal angle to the sun, although the movement of the sun during the day allows for a certain degree of flexibility. For central Europe a southern orientation at an angle of 30 to 35 degrees to the horizontal level is optimal. However, a module oriented vertically to the ground or oriented at the ideal angle towards the east or west still delivers 75 percent of the optimum value.

It is very important that a photovoltaic plant is constructed in such a way that it is not shaded by trees, neighboring buildings, or the geometric aspects of the building that carries it (roof projections, moldings, and bay windows etc. with regard to facade-mounted systems. or chimneys and the like with regard to roof-mounted systems). Apparently low shading can bring down the whole installation, as a shaded cell represents a high electric resistance in the system.

4.4. Module Performance & Data

The concept of efficiency signifies the amount of electric output of the module or cell in relation to the total radiation input and is given as a percentage. A part of the incoming radiation is converted into thermal energy and lost for electricity production. This leads to a heat-up of modules to temperatures of typically 60 percent. Theoretical values of efficiency are around 43 percent. Best laboratory values have been 23 percent, by using elaborate concepts. Values of commercial products are definitely lower, but work is in progress to improve the performance. Monocrystalline silicon modules presently show efficiencies of 14 to 17 percent, polycrystalline modules show 13 to 15 percent, amorphous modules deliver only 5 to 7 percent. Present thin-film modules have efficiencies of only 8 percent, but they use less material and are cheaper to manufacture in integrated factories and can thus compete with silicon in the specific price range, given in Euro per Wp. As a guideline, an efficiency of 10 percent means that a module of 1m2 under vertical irradiation at a clear sunny day delivers an electric power of 100 W.

A photovoltaic system is characterized by its peak power given in Wp (watt peak). This nominal power is the power which the module delivers under direct, vertical solar irradiation at an intensity of 1000 W/m^2, a defined solar spectrum (AM 1.5) and a cell temperature of 25^o C. A typical module has a nominal power of 10 to 100 Wp. Depending on the cell respectively module type a photovoltaic installation of a nominal power of 1 kWp requires an area of 9 to 20 m^2.

Another characteristic rating is given by the performance ratio (PR), meaning the yield of the system considered, and loss-free system of the same layout, nominal power and location. This value reflects the energy efficiency of all components and is influenced by the cooperation of modules, inverter, wiring and other system components, but independent of efficiency and orientation of the modules. The PR of modern plants lies at 0.7 to 0.8. A PR of 0.8 means, for example, that the system wastes 20 percent of electrical energy. Shading and dirt, but also high module temperature (caused by low cooling efficiency) leads to lower yields. State-of-the-art inverters have losses of less than 5 percent.

The energy payback time signifies the time the system (module) needs to retune the energy consumed for its manufacture. The balance is positive, if the payback time is less than the lifetime. Crystalline modules today have payback times of 3 to 4 years, thin-film modules of 1 to 2 years.

The harvest factor indicates the number of times that the system brings in its manufacturing energy. At a lifetime of 30 years the harvest factor is 5 to 8 for monocrystalline silicon modules, 7 to 14 for polycrystalline silicon modules and 9 to 21 for thin-film modules.

Photovoltaic modules have a lifetime of 30 years or more. (There are no comparable older photovoltaic systems) Manufactures presently give a performance guarantee of 20 to 25 years, which means they guarantee that the power output will deviate less than 20 percent from the normal power during that time.

4.7. Conclusions

Until now there are three generations of photovoltaics. The first generation is consisted of : monocrystalline and polycrystalline silicon cells, amorphous silicon cells, and hybrid silicon cells. The second generation is usually called thin-film solar cells because when compared to crystalline silicon based cells they are made from layers of semiconductor materials only few micrometers thick. The cells which are basically in the second generation are the amorphous silicon cells (a-Si) and the cadmium telluride (CdTe). The third generation of solar cells is being made from variety of new materials besides silicon, including nanotubes, silicon wires, solar inks using conventional printing press technologies, organic dyes, and conductive plastics. The goal in this generation is to improve on the solar ells which are already commercially available, by making solar energy more efficient over a wider band of solar energy, less expensive and used in multiple ways.

Since its inception, solar power technology has made constant progression. Advancements in photovoltaics have produced a more effective hybrid technology for solar panel engineering, and have helped lower the cost significantly. Continued scientific improvements have made vast steps in solar panel technology, including increasing the capacity to harness more solar energy per unit of surface area. This is a vital factor in panel technology because the more energy a solar panel can absorb, the more efficient the panel becomes at harnessing solar energy.

Today, solar panels can deliver at up to 22 percent efficiency and there have also been ongoing efforts to make solar energy even more affordable and efficient with an emerging technology called the "perovskite" solar cell (greenmatch.co.uk). A perovskite solar cell (PSC) is a type of solar cell which includes a perovskite structured compound, most commonly a hybrid organic-inorganic lead, as the light-harvesting active layer. Perovskite materials are named any material with the same type of crystal structure as calcium titanium oxide, known as perovskite structure (Navrotsky, 1998). This crystalline material could ultimately replace silicon in solar panels and reduce costs using simpler production methods.

Many breakthroughs have been realized the recent years. In 2016, MIT researchers were able to produce ultra-slim, flexible solar ells that are only 1.3 microns thick. These lightweight cells are promised to weight the same as soap bubbles, allowing future opportunities for use in certain technologies, like cell phones, while generating 400 times as much as the conventional ones (http://news.mit.edu). Furthermore, in 2017, MIT scientists have been built a different solar energy device that uses inventive engineering to capture more of the sun's energy. The device can, first, turn sunlight into heat and then convert it back to light, focusing within the spectrum that solar cells can use (https://www.technologyreview.com). In 2018, it was invented a product which combines the company Lafarge Holcim's concrete with a top layer of Heliatek 's flexible solar film that is just one millimeter thick (Figure 15). According to Lafarge Holcim, the product has the potential to double the energy generation that a building can achieve by traditional roof-based photovoltaics, because facades take up a greater area. The product weight less than five percent of a traditional solar panel and, beyond concrete cladding, it could be used with steel or glass. Simultaneously,

Figure (15): Lafarge Holcim's concrete with a top layer of Heliatek 's flexible solar film (https://www.technologyreview.com)

DAW and OPVIUS have designed a multifunctional façade system, in the plaster of the renovated building and it is a combination of active energy generation and passive thermal insulation. The façade not only includes an energetically valuable component but also experiences an aesthetic upgrading as a result of the organic photovoltaics. The system developed is transferable to all building types and façades , according to the companies, constructed with TICS today (http://www.opvius.com).

An addition to the third generation of photovoltaic cells are the organic photovoltaic cells which use an organic polymer layer to convert light into electricity. Is the first photovoltaic technology capable of generating electricity a low cost and it is easily manufactured by roll-to-roll process. Furthermore, organic photovoltaic have better performance in low light, can be transparent or colorful and provide greater flexibility and lower weight (http://solarmer.com, http://opvius.com) (Figure 16 &17).

Generally, as the years pass, more and more technological inventions in the sector of solar energy are going to be produced. From the graph (Figure 18) though, it seams that monocrystalline silicon is used less and multicrystalline silicon and thin-film technologies are more popular. Regarding the thin-film technologies (Figure 19), CdTe and CI(G)S technologies are being produced more, while the total global photovoltaic production have a downworth rate in the recent years (https://www.ise.fraunhofer.de). One certain fact is that more materials and the geometry of the module itself are the focus points of the future, in order to improve the efficiency (Figure 20).

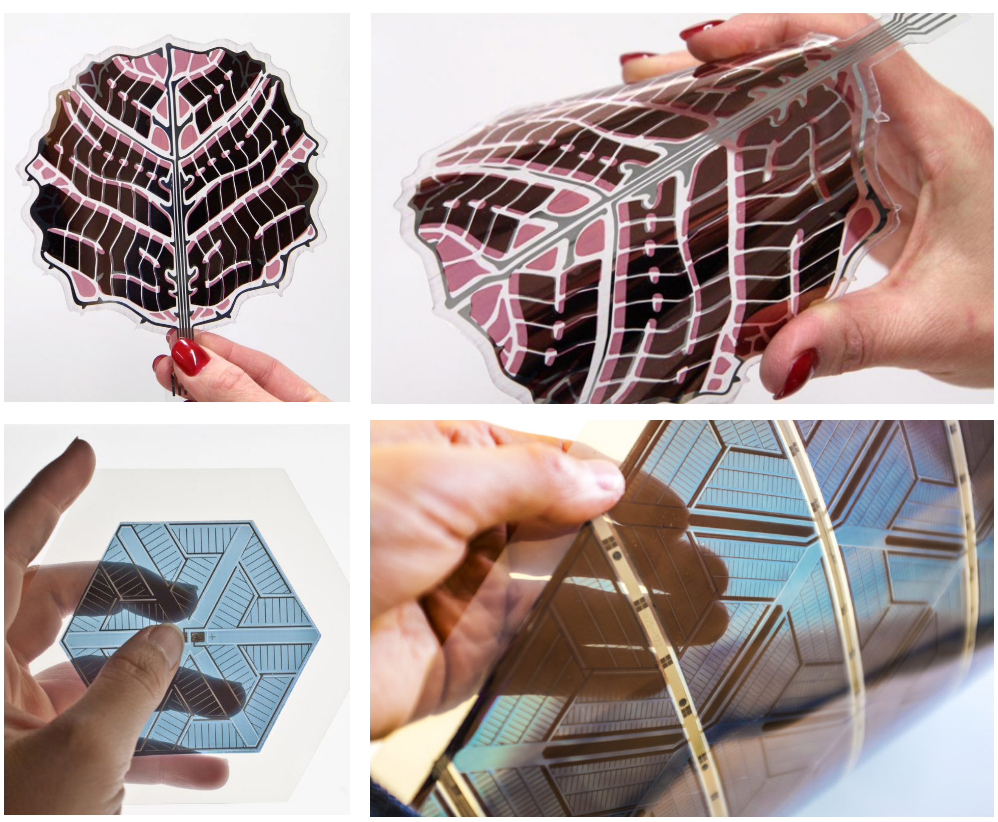


Figure (16 &17): Organic Photovoltaic Cells (OPV) (http://www.opvius.com)

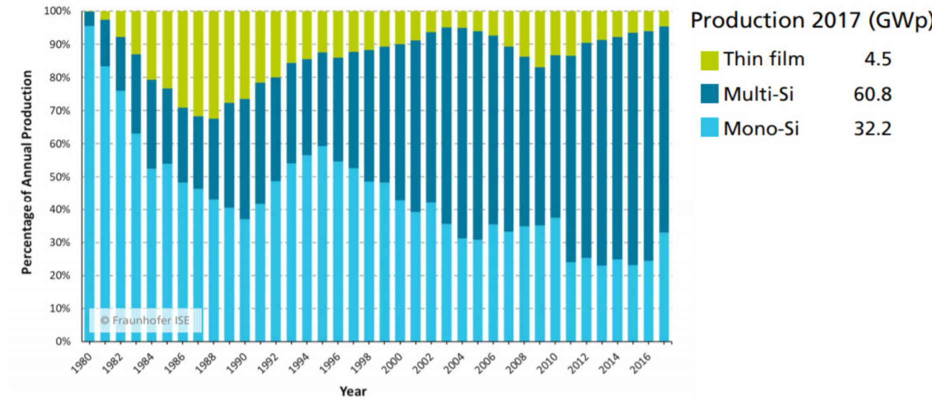


Figure (18): Photovoltaic Production by Technology, Percentage of Global Production (https://www.ise.fraunhofer.de)

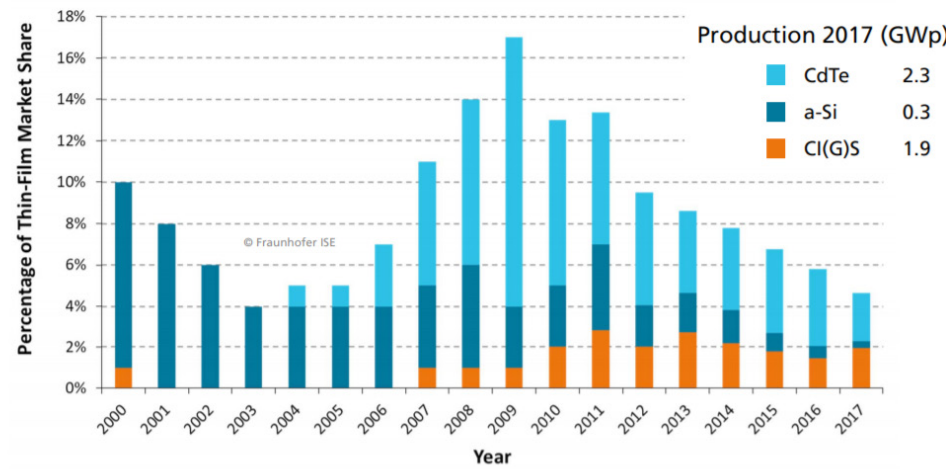


Figure (19): Market Share of Thin-film Technologies, Percentage of Total Global Photovoltaic Production (https://www.ise.fraunhofer.de)

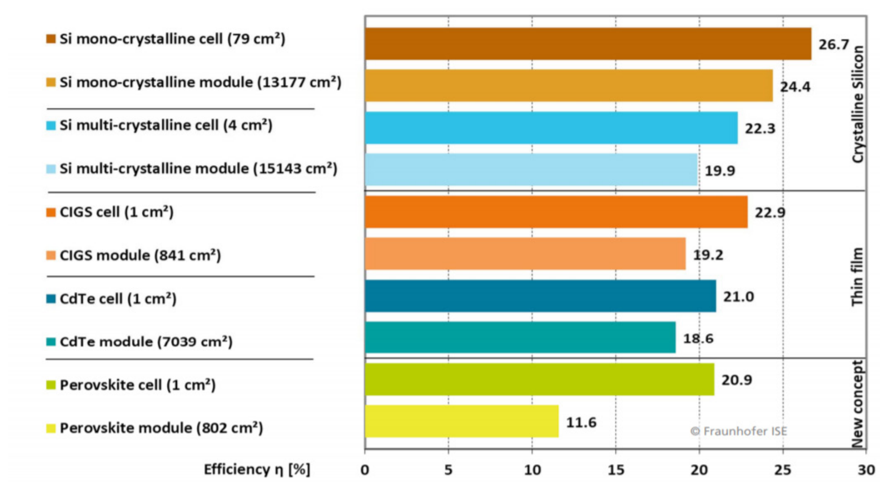


Figure (20): Efficiency Comparison of Technologies, Best Lad cells vs. Best Lad modules (https://www.ise.fraunhofer.de)

5. Solar Design in Heritage Buildings

5.1. Introduction

The widespread use of solar energy in tomorrow's architecture underlines the importance of concepts, both planning and designing. This contributes to an increase in public acceptance of the solar building through persuasive imaging and implementation and can be found in the "European Charter for Solar Energy in Architecture and Urban Planning", which was signed by well-known architects from all over the world (European Charter for Solar Energy in Architecture and Urban Planning Preamble, 1996) .

Basic fact is that solar energy installations are not considered to be exclusively technological systems that exclusively serve the purpose of producing heat or electricity. As an alternative, they should be considered and handled as components that make a significant contribution to architectural design and sometimes by replacing the original structural materials. So it seems that architecture can be enhanced, highlighted and distinguished from the surrounding structures. Thus, the latter can express adaptation and transformation, while preserving traditional characteristics, and can also give a truly positive image, both to the building and to those to whom it belongs.

The heritage world is a conservative one and could act negatively about new developments such as solar energy. In other words, heritage world has an image issue because the culture is the future that shows where we are coming from and distinguish two countries form each other, as the Dutch government has stated. However, the implementation of solar concepts in renovated buildings has failed, due to the difficulty of adapting the modern technological elements of solar installations to existing buildings, their dimensions, materials and decorative features in an aesthetic way.

Furthermore, an overlooked point is that the architects are often reluctant to incorporate photovoltaics to heritage buildings. In many cases, architects are just not familiar with the newest technological advantages and the financial implications, while the laws and guidelines do not give quite any green light to the solar application. In addition, the cost issue is usually a focal point that many investors promote, since the more special products are generally more expensive.

To increase the knowledge of solar application into heritage buildings, it is high time to promote and realize more well-executed paradigms of projects that are aesthetically appealing while delivering cost-efficiency and technological trustworthy balance. In addition, research has shown that, if the solar application is combined with renovation and construction material substitution, the cost of the whole operation and the end material would cost slightly more but would have higher appraised value.

5.2. Application Range

Installations on buildings that already exist, tend to be, inevitably, more fragmented in comparison with new buildings, as they have to conform with an existing framework. Since standardized products are often not applied to heritage cases, or applied but not well-matching, the situation requires innovative approaches. This concerns the design of the units themselves, but also, for example, the design of suitable sub-structures. In particular, this applies to heritage buildings, since technical interventions need to be minimized.

There are different types of solar energy installations that can be distinguish between free-standing or building-applied systems, and built-in systems or building-integrated systems.

On the one hand, in the case of free-standing installations, the external part of the system is located at short distance above the plane of roof or façade. This type is applied after the construction of the building is complete, as a result of which, sometimes, is not directly related to the building structure aspects (). However, with a surface-mounted installation, there is the least damage or loss to the original building material, both during installation and removal (Agentschap Onroerend Erfgoed, 2018).

On the other hand, the advantage of built-in installations such as power-producing slates or glass, is that they are integrated in the original plane, making them less noticeable. In addition, technological developments' goal is that these current-producing building materials visually resemble traditional materials that can be replaced. Especially, the glossiness, the structure and the color of the panels are being researched to match the traditional building materials. Building integrated photovoltaic systems (BIPV) are considered to be the functional part of the building structure or they are architecturally installed into the building design, and therefore serving simultaneously both as a building envelope material and a power source generating electricity (). For that reason, BIPV systems should fulfill the demands of both the building envelope material for construction and the solar energy production . The features, which are accounted for their use, are mechanical properties, durability and exposure to climatic conditions and building physical problems, like heat and moisture transfer in the building's envelope.

5.2.1. Photovoltaics on Roof

Because of the vast majority of the non-shaded position, the roofs are suitable for photovoltaic installation. This applies both to sloping and flat roofs. In this context, existing buildings suggest great potential for further development. Flat roofs are a good choice, according to technological requirements, due to the fact that they often provide large bonded surfaces and the orientation and tilt of the units can be optimized (Figure 21). In addition, installation and maintenance are possible without the need for a rack. Solar installations on flat roofs of reasonably high buildings are almost completely indelible from below and therefore can consist of standard products without any problems. A practical alternative is provided by solar pergolas, which can

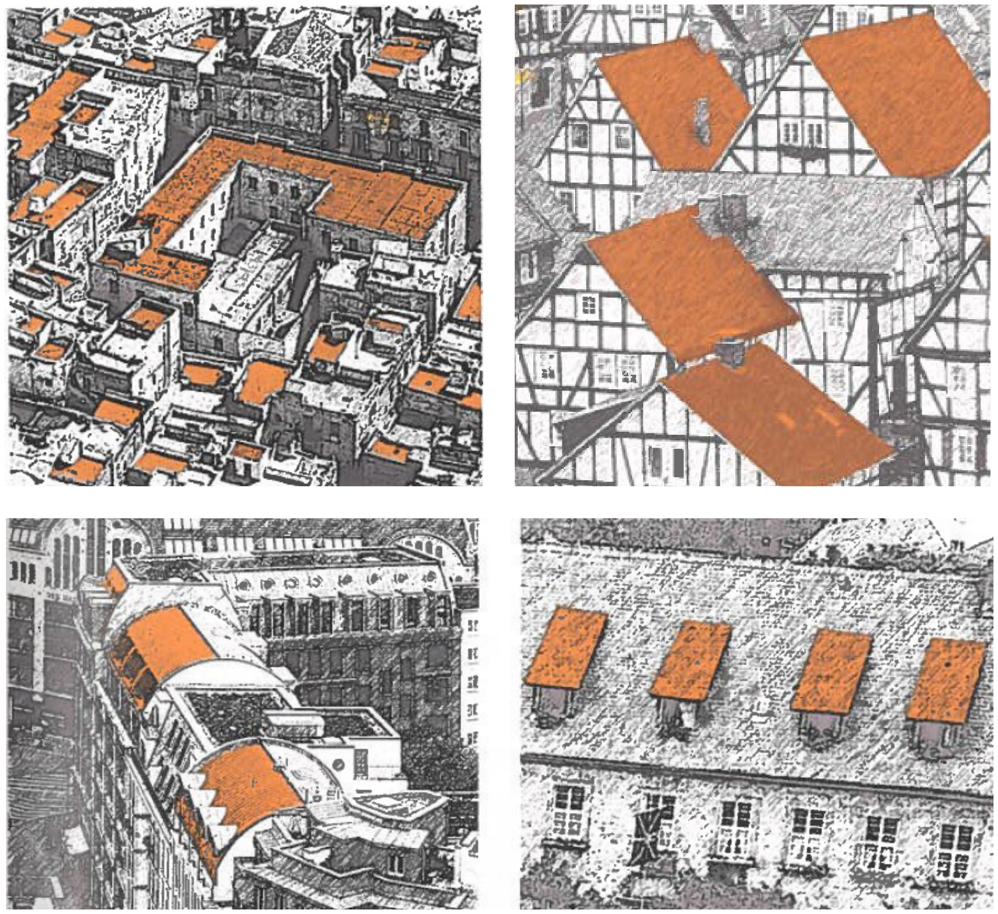


Figure (21): Examples of adequate placement of photovoltaic panels on roofs. (Hermannsdörfer & Rüb, 2005).

act as weather protection over the rooftops (Hermannsdörfer & Rüb, 2005).

The installations of photovoltaics upon sloping roofs, if faced in the right direction, can also produce considerably good energy yields. A wide range of products and systems is available to be integrated and attached and which can be found on the market. Typically, the additional weight of externally attached photovoltaic modules does not necessitate structural changes on the roof.

Photovoltaics can even be installed in vaulted roofs, provided that the unit sizes are adapted to form the curve. Alternatively, flexible solar cells can be integrated into curved units. This does not entail any particular size restrictions. However, there are optimal sizes in relation to some other technological elements of photovoltaic installations.

In cases of irregular roof surfaces, low energy requirements, or if large scale surfaces are not desirable for aesthetic reasons, smaller surfaces such as chimneys or roofs may also be used. In general, the individual structure and architectural design of the photovoltaic installation must come from the shape, color and material of the existing roof.

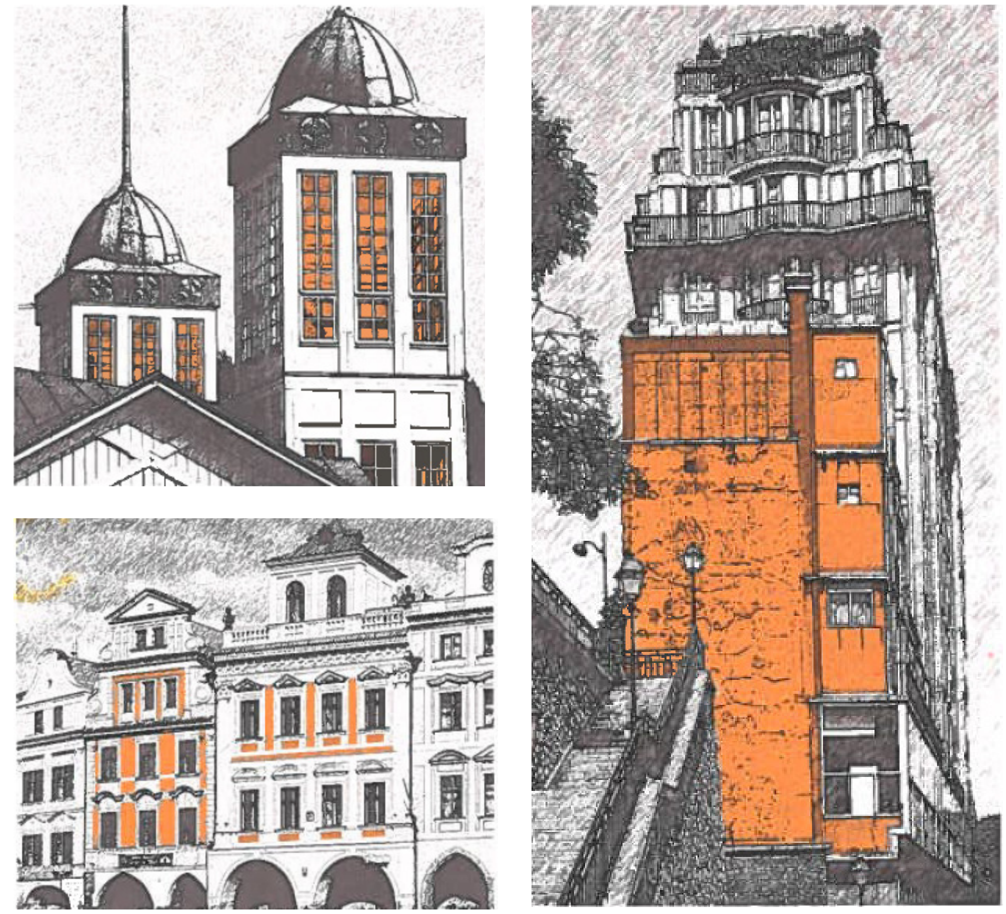


Figure (22): Examples of adequate placement of photovoltaic panels on facades. (Hermannsdörfer & Rüb, 2005).

5.2.2. Photovoltaics on Facade

Façade surfaces, with their variety, are also qualified for the photovoltaics' integration. It should be borne in mind that the vertical installation of solar panels is not as energy-efficient as the installation on sloping surfaces. However, a south-facing facade installation may still prove to be more efficient than roof units that are partially shaded or do not point south, south or southwest.

The integration of photovoltaic installation on an existing façade differs depending on the state and architecture value of the building (Figure 22). Until some years ago, regarding the structures made of metallic structures with masonry, framed by concrete, the conversion of photovoltaic panels into facades is a process that was almost unacceptable. The scenario is more difficult in the case of pre-industrial buildings with walls of masonry or wooden structures. In these cases, the corresponding historical modular systems of the building often do not correspond to the dimensions of the standard photovoltaic modules. Therefore, specific solutions need to be implemented (Hermannsdörfer & Rüb, 2005).

A facade design incorporating photovoltaics can lead to larger-scale or fragmented syntheses, depending on the style of the building and the design aspect. The outer wall surfaces, for instance, are well-suited for large-scale applications, while balcony doors, spaces between window corners, sliding doors and access galleries, among others, are suitable for fragmented applications. Structural components, especially those providing protection from weather, sun or vision, such as shutters, awnings and pillars, are also offered for photovoltaic applications. Semi-transparent units provide solutions in this context. By installing them into the windows, they can undertake an additional function as solar shading.

5.3. Architectural Design & Construction

The architect, who is responsible for a renovation project, should take into account many factors. The analysis of a building or its framework is not limited to aesthetic, morphological and historical aspects, but also includes the operation of the building and the climate requirements of the space and the energy supply resulting therefore. This defines the nature and extent of the project and its expected costs. Basically, a photovoltaic integration design must take into account three different aspects: energy engineering, architectural design and structure.

With this in mind, photovoltaic cells should not be considered as mono-functional technological objects but as design elements since they are part of the buildings' structure and sometimes are replaced other construction materials, like roof tiles when they replaced by solar modules. This also applies to heritage buildings, where the integration of photovoltaics is rarely considered by building owners or monument protection authorities, although further technical modernization of the technical services for the further use of these buildings is required. Therefore, in the early stages of a renovation project, it is considered preferable for the architect and the case, to establish close contacts with the qualified authorities of protection so as to discuss, control and coordinate any option.

5.3.1. Energy Engineering

The energy-conscious rehabilitation of an old building is part of the general strategy aimed at preserving the constitution of the building and restoring its original appearance. This process normally involves the alternation of individual building components and may include measures such as the insulation of the building shell (facade and roof), the application of passive energy principles by means of larger, highly insulated windows and the use of low energy appliances. Additionally, the client may opt for a new environmentally friendly system for hot water and power supply based on solar collectors and modules.

The choice of power system (either grid-connected or independent) and the size of the photovoltaic application should be based on factors such as local climate, location and function of the building.

5.3.2. Architectural Design

When dealing with an existing building in architectural terms, the purpose is always to refer to its historical aspect. Essentially, the installation of a photovoltaic facility can be based on three different design approaches:

- Opposition between old and new elements, the latter being introduced consciously as an independent layer
- Dialogue with and contrast to the existing structure by re-inventing and developing it.
- Restoration of the original appearance and inconspicuous blend with the new, modern elements.

Opposition and contrast, which in this case imply difference rather than dissonance, make a broad spectrum of photovoltaic applications possible. Highly technological components, such as solar panels, are particularly well suited to highlight the distinction between old and new through the use of opposed materials. Photovoltaic installations, that engage in a kind of dialogue with the existing situation, respect the original state while, at the same time, they are offering a creative re-interpretation of its natural and specifics. In many cases this will involve varying the panel sizes, so that the grids and shapes adapt to the existing roofs and facades. Further fine-tuning of the technological elements is required to reach an inconspicuous blend of old and new components and a symmetrical integration with the existing structure. In this context, surface structure, texture and color tones are essential visual characteristics to be considered.

5.4. General Aspects

The composition of the solar panels has to be informed by the building proportions in order to avoid an arbitrary allocation of modules, which may have a negative effect on the overall appearance. The modules on the facade may be placed differently according to the architecture of the building: appropriate areas are horizontal strips below or above windows, cornices or vertical zones structured by pilasters. If the solar panels are not supported to cover the entire roof area, they can also be positioned on separate areas such as dormers or canopies, or alongside the upper or lower roof edges.

The life-expectancy of a photovoltaic facility is estimated at around thirty years. Accordingly, the corresponding sub-structure and fixings have to be made from durable materials, such as aluminum, stainless steel or galvanized steel. Ventilated roof and facade structures will help prevent condensation or heat accumulation behind modules, which may affect their performance negatively. Careful sealing is required in order to avoid the corrosion of the connecting elements.

The same care and attention must be accorded to all three levels of the design process to be able to assess the correlations, interdependencies and emphases of the design and to achieve a result that is equally satisfying on all these levels.

In constructional terms, the installation of photovoltaics can be sorted out in three categories: Attachment, addition and integration. However, all three categories blend smoothly into each other. Attachment of photovoltaics denotes the reversible attachment of solar panels, as an extra element, in front of the outer shell of the building. This method is frequently applied when equipping buildings without the need for further renovation. Provided that an appropriate sub-structure is used, fixing as well as the dismantling of the solar panels is possible with minimum impact on the building. In the case of listed monuments, such attachment will often represent the only applicable method which convincingly meets the requirements of the building permission authorities for minimal intervention.

The addition of solar panels means that they form the exterior layer of the building shell, as summing some of its functions. In such cases dismantling the panels without replacing them would be impossible. The photovoltaic panels ,here, are presented as multi-purpose building elements. They may assist as solar protection in front of windows, as a canopy above the main entrance or provide visual protection in balustrades.

Both the shading of interior spaces as well as the energy efficiency of a combined photovoltaic shading system can be optimized by using a tracking system that follows the daily and seasonal course of the sun. Ventilated photovoltaic facades provide a good multifunctional alternative to the frequently used natural stone facades and can fulfill representative functions as well.

The integration of photovoltaic modules involves those becoming fully functioning parts of the building shell. The integration of photovoltaics therefore requires a holistic product development, for instance of compound modules that assume all functions of a roof surface (either as small ventilated roof modules or large-scale non-ventilated roof elements. Other solutions include photovoltaic cells integrated into thermopane glazing and providing anti-glare and eyesight protection, or solar double facades which power air-conditioning during the summer and contribute to the heating in winter through the heat accumulated between the layers.

In the long term, addition and integration are the more economically viable solutions. When compared to the attachment method, these application types require lower financial investment, as they are less material-intensive and the photovoltaic panels fulfill dual roles as both power generators and parts of the exterior building structure.

5.5. Innovative Cells & Modules

Even that the photovoltaic technology exists from 1954 when Bell Labs have been first demonstrate of a practical crystalline silicon solar cell, the “traditional” modules that usually used are the standard modules in dark blue or black color, visible metal conductors and shiny surfaces. Therefore, as efficiencies reach their theoretical limit, the search continues for new materials and methods to increase efficiency and decrease cost . However, in order to integrate photovoltaic technology in buildings and especially in those which have to follow architectural regulations, like the heritage buildings, creative approaches are necessary. The new designs should correspond to the architectural character of the monument. At the same time the sensitive application of them is huge factor, as much as the financial and technical feasibility ().

The cooperation of all sectors, from the idea to the market, aim at the development of smart solutions with minimum technical intervention and maximum adaptability. There are many generations of photovoltaic technology and the modules show great variety to the properties as much as to the price range.

Thin-film modules are preferred to crystalline silicon modules as basis for the development process, because they appear to be more homogenous and thus are more adaptable to different scenarios. In addition, monocrystalline solar cells can be integrated into different materials and shapes giving thus the possibilities of using variation .

In the past the possible modifications were used only to the front glass panels of CIS modules which can be under less thermal stress during the production process. However, new production developments on CdTe modules are focused into new innovational design, for example the development of modules which could be adapted in size on the building site (“cut-to-size modules).

In addition, semi transparency is possible to both of the above technologies. Moreover, monocrystalline cells, which can be treated with different techniques to reach semi transparency, are used for different applications like “solar flags” and pergola elements. That makes them even more adaptable to different shapes and can mimic different materials.

5.6. Selection criteria for photovoltaic modules for application on heritage buildings

Integrated photovoltaic technology in buildings could appear with many faces in facades and roofs. However, the design of the suitable modules for heritage buildings is particularly limited. That is because it is not just a common facade or roof, but these specific structures are arranged by laws and limitations. Thus the selection of the most suitable properties is vital for the integration of the photovoltaic technology but also for the building itself to the building environment. These criteria consist of a properties list that they can adapt to the architectural character without much lack of performance of the module.

5.6.1. Color & Pattern

The color is one of the most important principles of the photovoltaic selection. Usually the “traditional” photovoltaic color, blue, green or black, seems an alien to regular buildings and even more to a listed one and generally they don’t blend in with the building environment, except if the building designer has considered from the beginning the color of the photovoltaic. There are physical reasons and technical limitations that the color range of solar cells are blue, black or green. Thin-film solar cells are consisting of amorphous silicon (CIS) are black and CdTe cells have a greenish

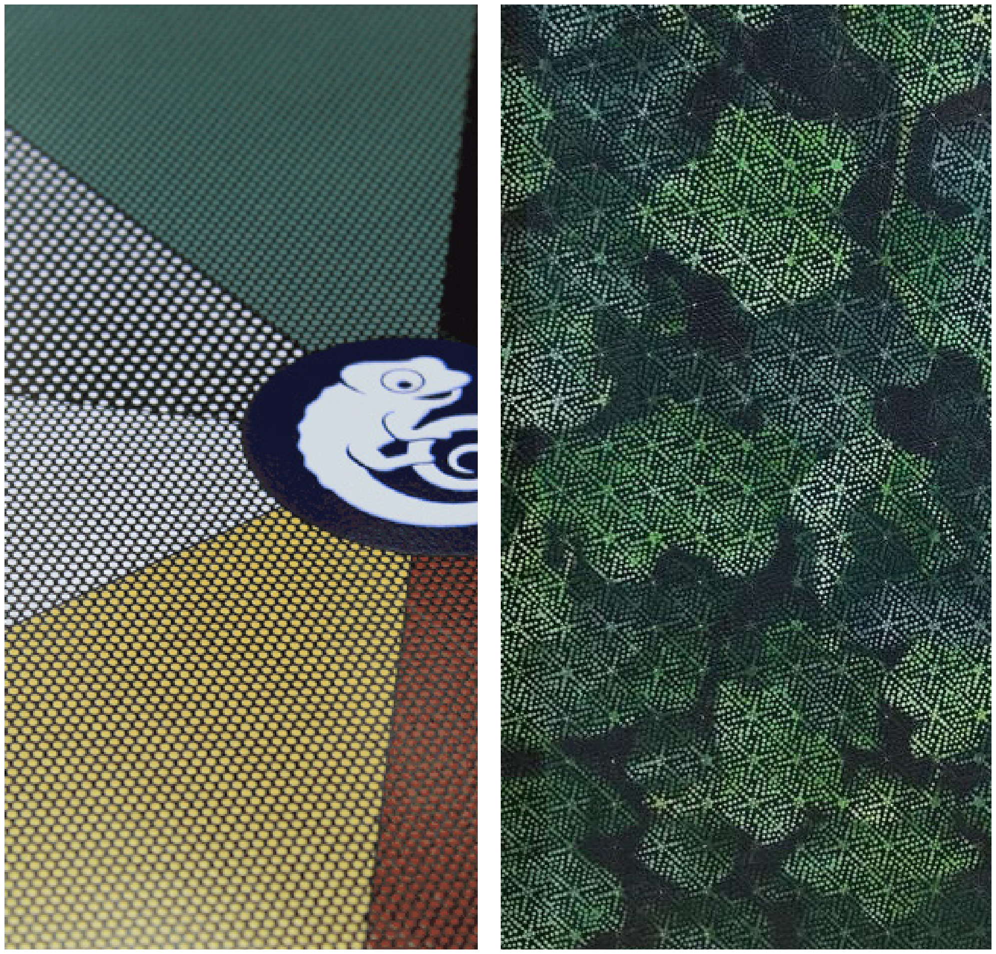


Figure (23): Example of ceramic screen-printing. (Kameleon Solar https://kameleonsolar.com) (left), (ECN_TNO https://www.unstudio.com)(right)

shimmer and even though the color can be altered without changing their technology, extra steps have to be added in the production process generating more cost (Hermannsdörfer & Rüb, 2005).

Ceramic screen-printing

A first method of changing the is by ceramic screen-printing in which any kind of pattern or color can be produced (lettering, logos, information, or mimic a materials view). The required pattern is printed onto the cover of the module in a regular grid in order to sustain full functionality of the module (Figure 23) . However, the energy yield is going to be reduced in an analogous percentage of the printed grid. The more dense the grid is, the less energy production. The prototypes usually had a 10-20 % of printed surface and thus less energy yield (Hermannsdörfer & Rüb, 2005).

When designing the printed pattern, the original cell color must be considered because it affects the final overall color appearance. Thus the final optical color impression is created in the viewer's eye in relation to the dark background. In order to have the desirable result, brighter and brilliant colors must be used than the original optical example. In addition, the optic filters provide great variety and highly saturated colors, as much as they are commercially available and multifunctional.

Colored cells

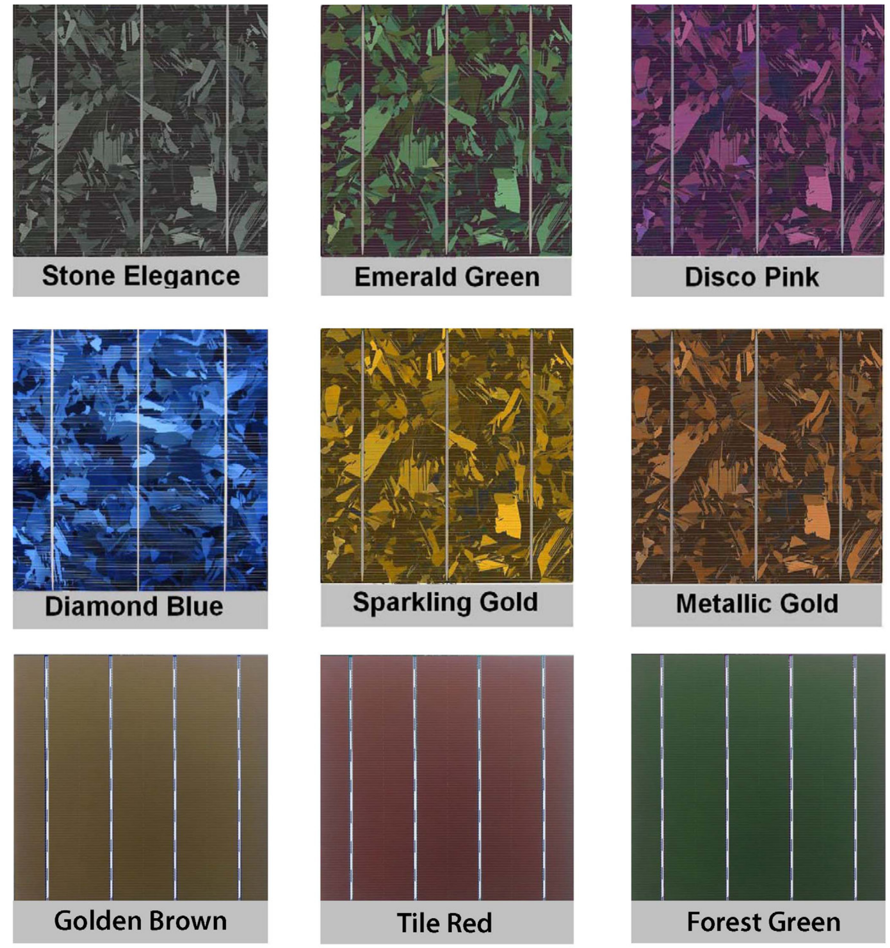


Figure (24): Colored cells with marble effect and simple color (http://www.lofsolar.com)

Except printing on the outer glass, there is also the option of colored cells, a development by a Taiwanese brand LOF Solar (Figure 24). They have developed monochrome and marble-effect modules with a variety of colors. On one hand, the classic series consists of five matt colored modules with fixed color from every angle of observation. On the other hand, the marble series consists of 5 colored modules with high sparkling effect and changing color by changing the light. Their efficiency is 75-80 percent of a standard module even though the matt series could produce higher outputs.

Terracotta-like modules for building integration

The last decade, several projects have risen the subject of adapting solar modules to the terracotta-like color, due to the urge to hide visually the modules in order to be acceptable easier, especially in heritage building cases.

There are two different approaches that usually followed to demonstrate terracotta-like modules:

The first one is called interferential filters, which are using a colored coated glass which is laminated on the top of the glass of the thin-film module. To change the module's color, an optically selective filter is applied to the inner side of the front surface structure. Limiting energy losses, this filter reflects only a selected part of the incoming radiation. The stained filters composed of multilayered thin films and have to be optimized to incorporate an intensive color with a high energy performance. This interface filter consists of a superposition of transparent oxides. To adjust the

Figures (25) : Orange glass panels laminated on real-size PV modules on which strong angular dependency of the color is observed.

Figure (27) : Visual appearance of the amorphous module after exposure to PID. Left: condition without protecting tape after 300 h. Right: condition with protective tape after 500 h.

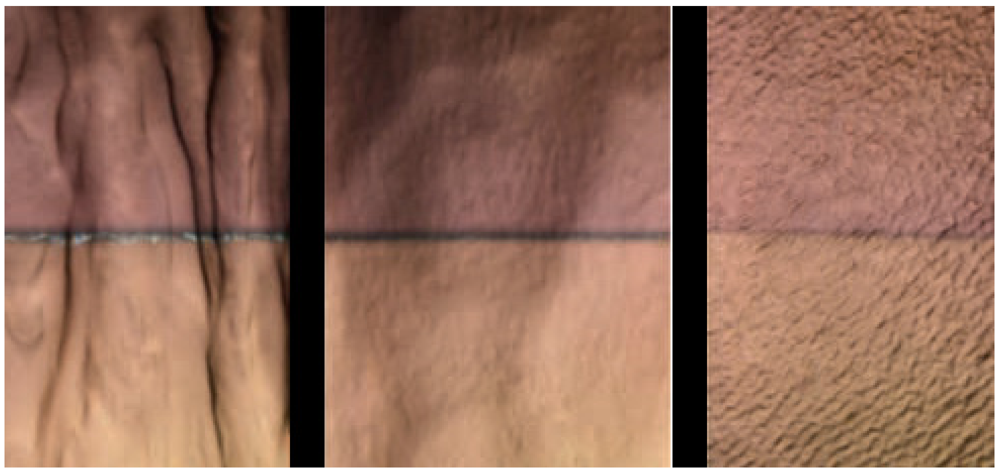


Figure (26) : Combination of industrial Flachglass texturation (from left to right: Silvit Weiss / Kathedral C Weiss / Spez. 33 weiss), chemical etching and interferential filters made in LESO PB.

Figure (28): Terracotta-like colored hotovoltaic modules by ARCHINSOLAR

appearance of the module to its environment, an etching treatment is applied to the front structure. Then, a special chemical treatment of the outer side of the front glass produces a textured appearance, while diminishing light reflection (Lutz & Scherrer Institut, 2018). When the first generation was developed, in order to prove the visibility of the concept, it revealed the absence of angular color stability of the coating which was solved partially with new simulations (Figure 25). In addition to that, several reliability studies needed to be performed for certification, including accelerating aging and mechanical tests (Figure 26). Special observation was directed at potential degradation from exposure to heat, humidity and voltage. The tests conclude that by adding a protective tape to amorphous modules, the visual appearance has less degradation (Figure 27).

The second one is the adjustment of the solar cell thickness in addition to a specific colored encapsulant. The terracotta-like color matches the orange of a selected Braas tile, which is the most installed tile in the French part of Switzerland, chosen as reference and even various tonalities of orange can also be produced. The company ARCHINSOLAR has been produced these modules industrially by a thin-film company in 2013 and the modules has been installed as a demonstrator on the roof of a heritage building in Neuchatel (Figure 28) (Lutz & Scherrer Institut, 2018).

These colored changing methods in semi-transparent amorphous silicon (a-Si) modules were researched also on the way the colored encapsulant was performed. The two solutions to investigate were the front-side coloring (first method) and the bask-side coloring (second method), and they were compared to a reference encapsulation scheme. The color rendering can be turned by either by placing an interferential filter in front of the module (front-side coloring) or by using a colored polymer behind the semi-transparent a-Si module (back-side coloring) (Figure 29). The results of the tests revealed that the front-side coloring is more efficient electrically than the back-side coloring, due to the fact that the placement of a colored encapsulant layer on the back of the cells lowers the back-reflection effect, while placement of an interferential filter in front of the cells reduces the total solar power that is transmitted to the cells. However, front-side coloring schemes suffer from a strong angle of vision reliance of the color, which can be improved by interferential filter, while back-side coloring exhibit more stable colors (Lutz & Scherrer Institut, 2018).

Generally, the darker the material, the most sunlight is absorbed and therefore it is better in energy yield. When color is added to a solar panel, it becomes less efficient, as they reflect the wave of the color that they are and thus less solar energy. Sometimes, the color may be not consistent at different angles of observation and can be highly reflective. Moreover, the modules are relative expensive due to the manufacturing process and they lack of efficiency. Each approach has different efficiencies and often different colors. Even though these modules are less efficient than the “original” one, they can adapt better to the urban environment by mimicking the materials of the surroundings.

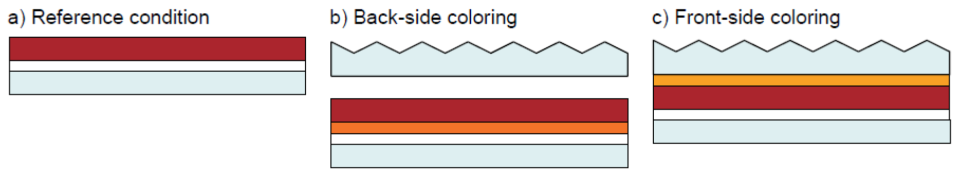


Figure (29): Schematic view of different encapsulation schemes.

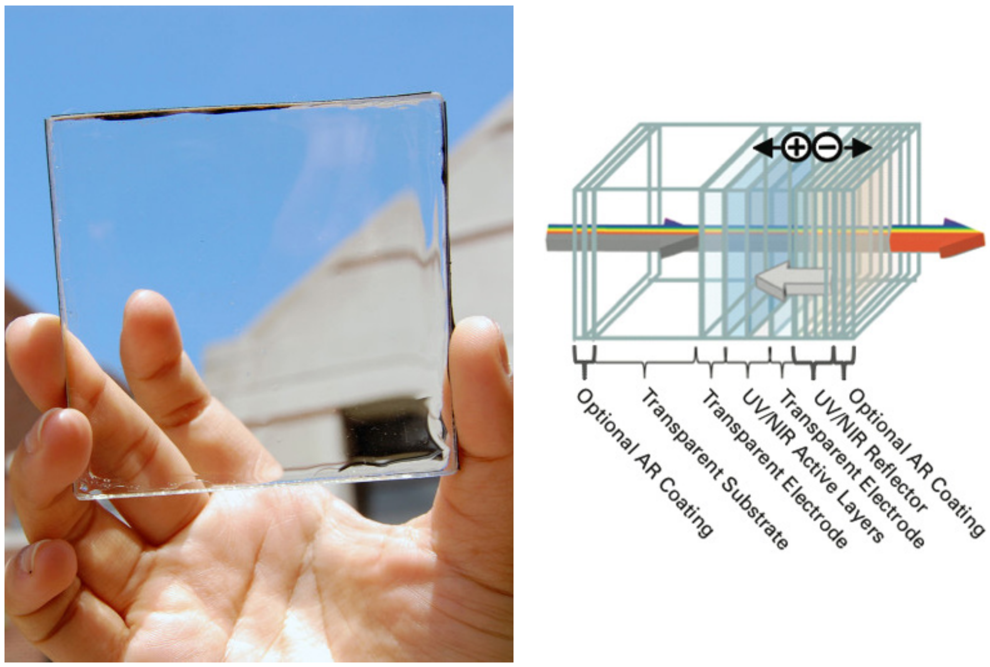


Figure (30): Transparent photovoltaic (MIT) (http://energy.mit.edu)

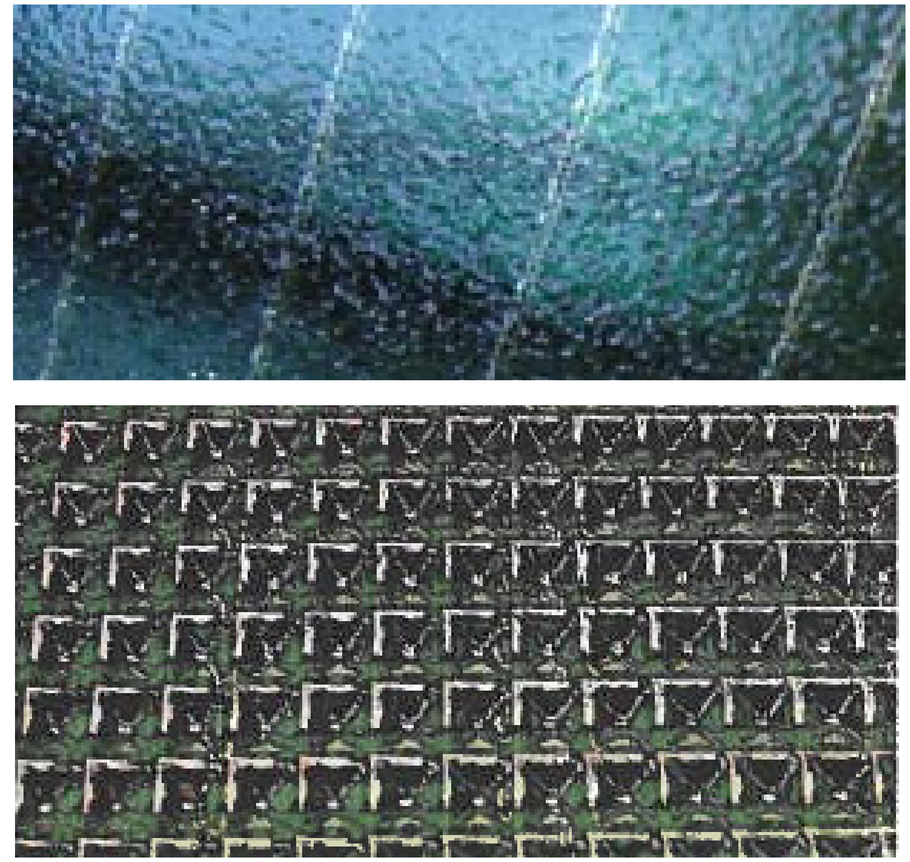


Figure (31): (from top) Prismatic module surface (ANTEC Solar), Module with matted appearance of structured glass surface (ANTEC Solar), Matted surface with light-gray appearance and randomly chosen pattern (Wǜrth Solar) (http://www.pvaccept.de)

5.6.2. Transparency

Semi-transparency is an important property of a photovoltaic cell or module, as it opens new fields in architectural integration providing the designers with a variety of applications. Depending on the amount of transparency that each module provides, there is an interesting shadow pattern from the elements of the module to the interior. The transparency is created by using thermopane glazing or an additional sheet of glass or even plastic. These cells are combining the properties of power generation and natural lighting and can have a vast range of applications, from window integrating to street furniture. The processes to produce semi-transparent cells are by spacing the embedded cells at larger distances from each other or by mechanically modifying mechanically the cells using laser (milling or scratching). In this way, patterns with variation are created to produce a broad scale of semi transparency (Figure 30).

However, it is important to mention that all semi-transparent variations are less efficient comparing with the original one because they have reduced the active surface of the cells. For that reason, it has to be taken into account the energy yield and the required surface area in order to reach the desirable energy production.

5.6.3. Surface Structure

The surface structure of a photovoltaic module, which is usually glass or plastic, form a contrast between the shiny cover and the matt rough filling of building materials like brick or teracota. In addition, the cover materials reflect the light and usually create undesirable glare. The PVACCEPT, a research project on solar energy in Berlin, tried to resolve more this issue with various experiments on cover glass, in order to achieve convincing results without compromising the performance of the modules (Figure 31).

After the experiments, it is proved that sandblasting is one of the suitable processes to create matt surfaces that also give the possibilities to a vast of regular and irregular patterns. In addition, after the procedure, the cover appears as a light grey color which could be combined with very bright facades.

Another suitable process proved to be the use of structural glass in many types. Within the experiments of PVACCEPT achieved one uncommon feature. The CdTe thin-film module is covered by a figured glass with a pyramidal surface structure. The result of the test was that the dark green color of the module was brighter by the light refraction and appeared as bright green. Moreover, the shades of the module changes under different angles of incident light. As they conclude, this particular module could be suitable and very adaptable to use in natural landscapes. This new application could be easily be available and cheap because the production process doesn't change much from the normal one. However, the figured glass may collect dirt more easily than the smooth one and it is believed that is going to affect the performance of the module.

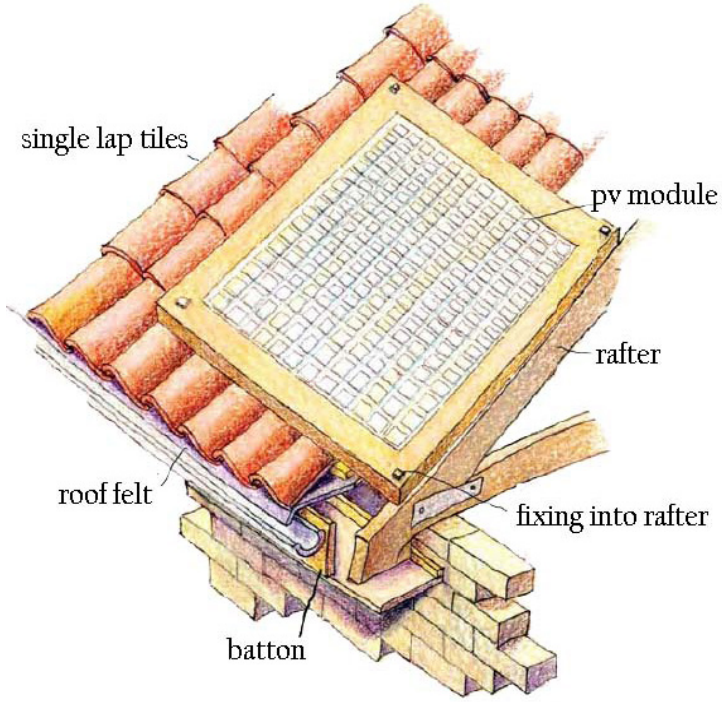


Figure (32) : Cross-section showing solar module fitted over covering (Heritage England) 2018)

Figure (33 : New thermoplastic composite material and a molding process

Figure (34) : "Solar flags", Castello Doria in Porto Venere in Italy (2004) (http://www.pvaccept.de/eng/portovenere.htm)

5.6.4. Integration System

The integration system is a very important aspect since can define the visibility of the module, the life circle of it, but also the impact that has on the applied building (Figure 24). The ARCHINSOLAR has produced the developed modules (seen in the chapter "Color & Pattern") in order to check the installation and compatibility of them. The installation allowed confirming the validness of the concept but revealed limitations of the prototypes. The main issue was the "thickness" of the module, which was less than the actual cement tile, even though there was a solid exhibited "front" interface. The process that followed consisted of the development of new round of prototypes with actual thickness of the tiles at all four sides, modified surfaces for better positioning and support on the wooden beams of the roof structure. Also, it included special slots for fixation screws and washers, and rounded edges for easier manufacturing and hand protection. In addition, a new thermoplastic composite material and a molding process were introduced as cost-effective solutions to produce solar tiles fully compatible with building integrated pv (Figure 32) (Lutz & Scherrer Institut, 2018).

In addition to that, the same company developed a photovoltaic thermal collector (PVT collector) approaching the same sensible characteristics of the photovoltaic modules, like high aesthetical value. This hybrid system increases electrical performance, due to the cooling of the controlled cell by a thermal absorber on the backside of the PV module and increase thermal performance due to backside insulation by building insulation material (Lutz & Scherrer Institut, 2018). This system was tested by prefabricating it in the lab. One of the tests was thermography in order to measure the various radiation intensities over the BIPV. The temperatures within the underneath cavity and at the front-side of the module were monitored with thermocouples and IR camera. The measurement is repeated under various upstream velocities, radiation, intensities, cavity sizes and arrangements (Figure 33) . As it can be seen from the figure, the smaller the dimension of the module, the less temperature is rising, and consequently the longer the life circle.

5.6.5. Cut-to-size Modules

The PVACCEPT research program developed cut-to-size module prototype that aimed at providing modules, whose size is adaptable directly on building site in order to solve the tolerances in dimensions of old buildings. In this module, the substrate glass was laminated onto a larger pane of glass, after its coating with cells, and not as usually onto a pane of the same size, as it usually happens. This resulted to leave extra material of glass around the module on all sides and so the module could be cut by hand without damaging the cells. This invention is possible to create interesting architectural effects in the integrated photovoltaic area.

5.6.6. Multifunctional Objects

The thin-film technology provides the designers with many variations of photovoltaic technology in order to choose what is suitable for their concept. In the PVACCEPT research program, a particular object has been produced, called “solar-flags”. These consist of special semitransparent, grey solar cells which are embedded between slightly bent acrylic glass panes. The elements can vary in size and number and they are luminus at night by LED lighting. The specific application was integrated in the inner courtyard of a listed monument Castello Doria in Porto Venere in Italy. The “solar flags” were hanged on steel wires in the arches of the wall (Figure 34). This application is also approved for “solar trees” and “luminus canopies”, as it is suggested by the research program.

In addition to the thin-film family photovoltaic modules, KS Flex offer high performance of monocrystalline solar cells in lightweight, semi-flexible package. This is a custom-made solar panel and instead of using a front glass carrier, is fitted with a polymer front sheet without any frame. This alteration decreases the weight of the module, providing at the same time some flexibility on a module level. The efficiency can be up to 98 percent of a standard module.

“Solar canopy” elements also permit a flexible range of uses and variations in the design. They can incorporate in the urban space as “solar seats” (Rotterdam and Veenendaal, in the Netherlands) or simply as canopy in places that should provide shelter from the weather conditions like the bus stops in Berlin (“smart bus shelter”).

5.7. Conclusions

As it was presented in this chapter, the photovoltaic technology can mimic color and texture, decrease glare, increase transparency and performance with multifunctional use. As it can be concluded from the above characteristics, there are several techniques that allow a huge amount of aesthetic options and varieties, even with the same solar technology. Each one has advantages and disadvantages depending on the range of the application. Generally, they are economically feasible and color constraints will not be an issue in the near future.

Each application is a new challenge, especially in heritage buildings, where the different applications and the overall design should correspond to the architectural character of each case. Fortunately, technology offers a variety of options to decide from. Sometimes, maybe the design concept should be compromised by e the efficiency, but together with a potential energy efficient restoration plan, most of the buildings could again be fashionable and help the building environment to full energy transition.

6. Application aspects and evaluation criteria of reference cases

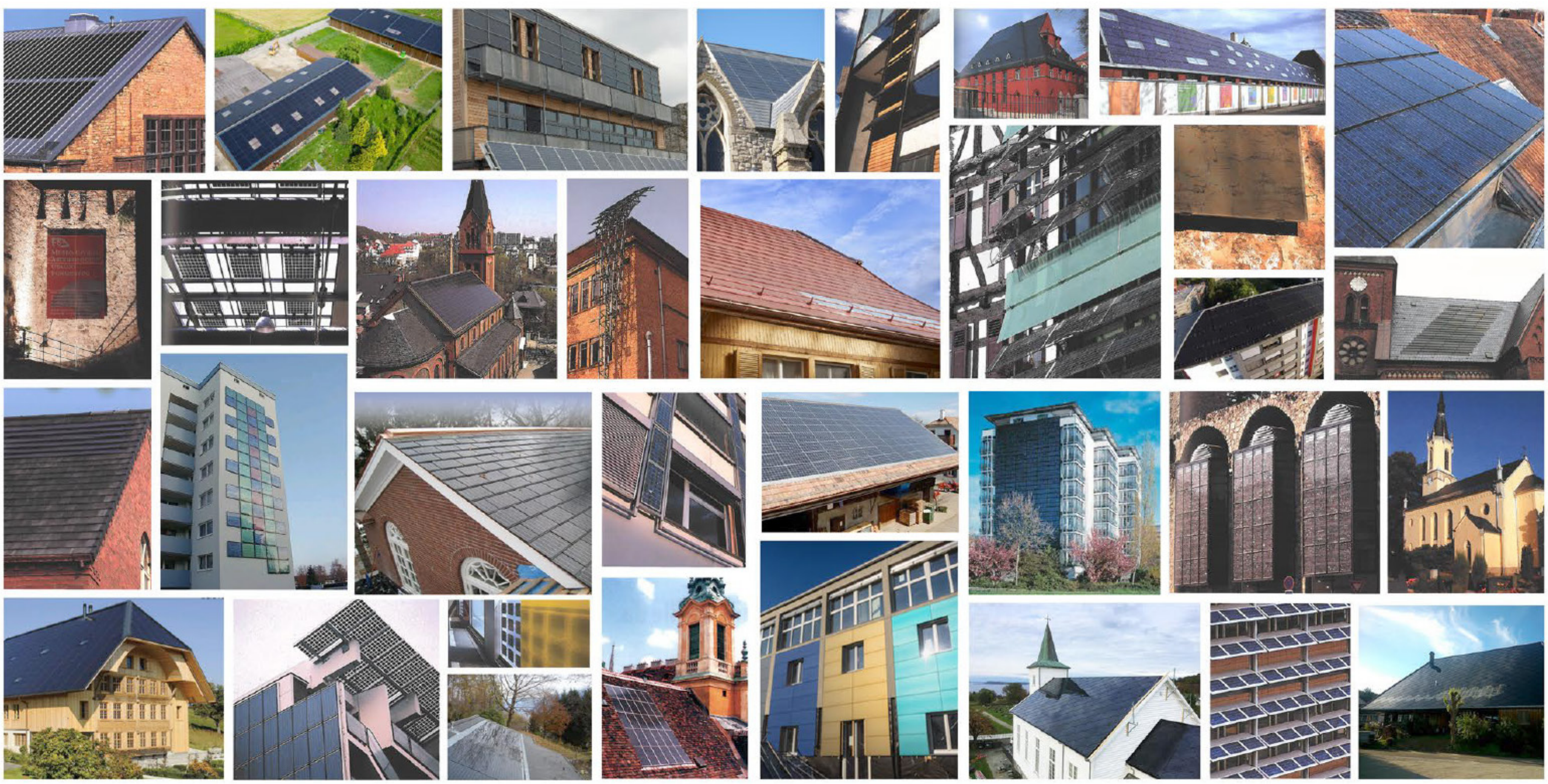


Figure (35) : Reference case studies_ Photovoltaic Application on Heritage Buildings

6.1. Introduction

In this chapter, the characteristics of sixty cases in Europe are explored in order to find out which criteria can be used to evaluate the applicability of photovoltaic technology to heritage buildings. These cases are heritage buildings on which photovoltaic technology has been applied. The cases are ordered in categories depending on elements that characterize these in particular. A catalog of the case studies is presented at the appendix of this report.

However, as it happens in every research, in the evaluation of the case studies there were limitations. Firstly, the data from the sources were not complete enough, lacking information. The data that were usually missing were the existence of consultant, the area that was covered in photovoltaics and the number of active modules that were placed, because not every module is active in the series connection due to efficiency. In addition, the lack of information about the limitations that existed from the local heritage authorities were missing from every case and all that is known is the result of that.

It is very possible that there are many other cases that are not included in this research. However, this sample gives a vast of different information of how different cases in different time periods are treated and what is the end result despite the limitations and the guidelines from heritage authorities. This sample and the categorization of their characteristics, give the trigger to form evaluation criteria based on which the next experimental case study is going to follow, in Chapter 8.

6.2. Reference Case Studies

The reference case studies were, mostly, the part of justification that photovoltaic application is possible to heritage buildings and with success. The assemblage of the studies started with the book “Solar Design” (Hermannsdörfer & Rüb, 2005), where I found most of the cases that are evaluated in this report were found. The rest of the cases came from databases online where heritage cases were gathered and presented. The criteria which are followed for the presented cases, were, firstly, that the buildings should be listed and, secondly, the older the construction year the better. The latter was wisely chosen because the case study, which the evaluation key points would be applied on, is a listed building from the 20th century and therefore the application method on older cases was valuable to the approach that would be formed in a next stage.

Generic	Architectural	Technical
Location of the case	Area of application	Orientation requirements
Construction age	Typology of the building	Technology (PV generation)
Use of land	Color of the PV	Efficiency of the PV (colored or classic)
Hiring an architect or a consultant company for the application	Shape of the modules	Mountaining application
	Surface structure	

Figure (36) : Application aspects dirived from studying reference cases_ yellow highlighted are about the case in general, blue highlighted are about the photovoltaic module.

6.2.1. Application aspects

At a first glance, the criteria on which the evaluation on the case studies is based on, seemed subjective, such as if photovoltaic module application is “easy on the eye” or just a “necessary mean”. However, forming the criteria in depth was based on different aspects on the photovoltaic application on heritage buildings and also the way that they were fitted to the environment.

The color, the pattern, the extension of transparency and the optical reflection aresome of the first characteristics that differ between the cases. An extensive and detailed analysis upon the cases was formed in order to conclude to the different criteria that these cases are evaluated on. The division that was chosen was formed due to the complexity of the topic and so the application aspects splinted into : generic, architectural and technical aspects, and they will be explained extensively as following (Figure 36). The figure above explain is illustrate with yellow highlight the aspects retated to the case itself and with blue highlight the aspects of the modules which are being applied in every case.

6.2.1.1. Generic Aspects

The generic aspects consist of the location, use of land, and hiring a consultant company or an expert to apply the photovoltaic technology to the listed cases.

First of all, by examining the different locations of the case studies, automatically a list is conduced of the most energy advanced European countries in the solar sector. Germany and Switzerland have the most cases of application, owning half of the cases, followed by Austria, France, England, Netherlands and Italy. Other countries that they own the rest of the cases are Belgium, Spain, Denmark and Norway, but in small percentages. These conclusions derived from the table with all the cases in the appendix section of this research.

Regarding the use of land, the current program of these heritage buildings is mostly dwellings, around one third of the cases, while hotels own a small portion of the whole. The reason, usually, behind this result is the reduction in building energy consumption that the EU aims in 2050 (Energy roadmap 2050, 2011), and thus refurbishment but also off-the-grid cases are trying to convert to solar. Furthermore, the following dominant program is that of the church. Communities are very active to act in good faith, both for human and the environment. The Eco-church is one of the interesting movements that consists of churches which have been refurbished the outdated roofs and had integrated photovoltaic panels. That leads to the primary use of energy in the church itself but also, in some cases, to the spread electricity grid through the neighborhood electricity grid. The rest of the programs, that occupy the heritage buildings, have usually public or educational use, or even artistic installations and information boards, presenting the different ways that photovoltaic technology could be applied (Figure 37) .

Lastly, the use of a consultant company or an architect was one of the most unexpected results and that is because it was expected every case to use a consultant since the heritage buildings have to follow certain guidelines. Most cases appeared to have an expert to consult with for making the decision of the place and type of photovoltaic technology that is approved by the heritage authorities of the region. At the same time, in the rest of the cases only the technology provider was mentioned without any other information of consultation or no company mentioned at all.

6.2.1.2. Architectural Aspects

To illustrate the architectural aspects, the elements which define the architectural integrity of the case, have been selected. That consists of the typology of the building, the area of the application, roof or façade, the color and the shape of the modules.

The typology of the building is a broad category that is linked with the program of the building that was mentioned in above, in general aspects. Because the results were broad, and the rest of the structures were conventional and ready to host almost any program, the only typology which could be highlighted is the church typology. Driven by an ethical commitment to reduce carbon use, but also by the potential revenue from energy fed back into the electricity grid, several churches chose to install photovoltaic technology into the refurbished roofs, as mentioned before. The large south-facing roof slopes, which are part of the church typology in general, appear to be ideal for generating energy from solar photovoltaic cells. In addition, the module installation, in every case, required planning approval as well as listed building authorities agreement.

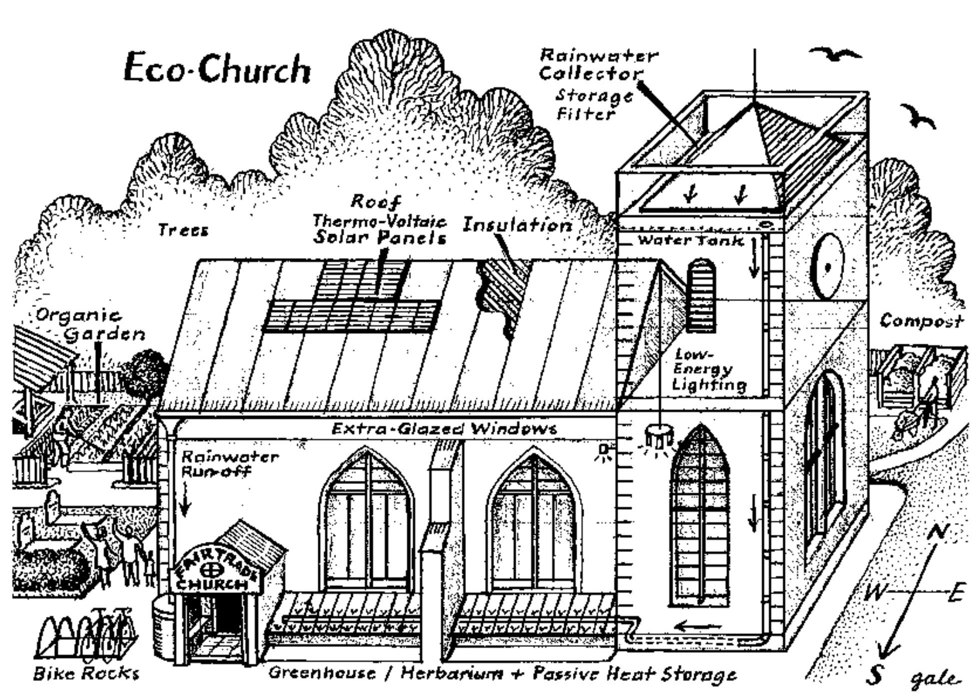


Figure (37) : Eco-Church https://ecochurchsouthwest.org.uk/

As for the area of the application, the possible installation in the building could be the roof, in a slope or not, and in the façade. In the cases that were evaluated, a quarter of them was only applied into the façade. Usually, as several mentioned, the façade application is more challenging to the heritage buildings, in contrast with the newly built structures of which the form could be adjusted to the environment for maximum results.

Regarding the color of the photovoltaic modules, about half of the cases appeared to have installed blue colored modules. This was usually encountered in cases in which the refurbishment happened before, like the “Reformierte Kirche” in Austria, or that the whole roof was covered with the same module in order to avoid optical differences (Figure 38). As following color modules are the grey and black and only 10 % of the cases are appeared to have different colors, like red, terra-cotta-like color and multicolored, with a pattern or not. Yet, regarding the shape of the module, every case had used flat shaped modules, used in a slope or in flat surfaces. However, there are modules from thin film that can mimic the wave of roof tiles. The fact that they are not in use , it is a point worth investigating more. Maybe the color blue of this particular module is not approved by the authorities or the efficiency is so low that the ratio between efficiency and cost, does not worth the investment. Two cases that there were different in placing the classic cells in a different way, belong to the company SUNSTYLE. In these cases, the module application is adapted to the North European roof slate style by placing the modules in a different way and which had the result of creating a harmonious pattern, almost like a fish skin. The cells were adapted to the new arrangement using the maximum surface possible. (Figure 39)

Figure (38) : "Reformierte Kirche" in Austria

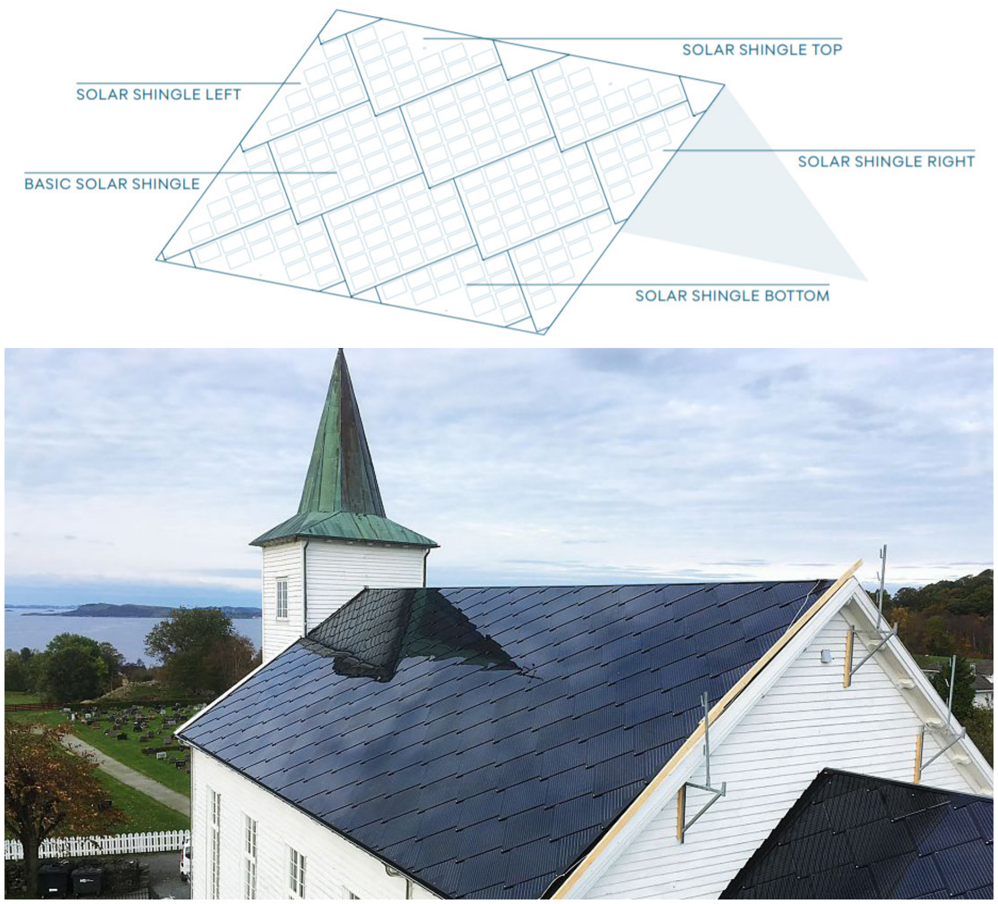


Figure (39) : Church in the Strand _SUNSTYLE module (https://www.sunstyle.com)

6.2.1.3. Technical Aspects

In the last category, the enclosed aspects are mostly about the efficiency of the photovoltaic modules in the different case studies. This consists of the orientation and inclination requirements of the application surface, the photovoltaic technology, that is to say, how advanced is the technology that is used to the module, the efficiency that is caused by the different color in the module, rather than the cell color itself, and the mountaining application of the module, which is to say how well integrated are the modules to the main structure.

The only thing that can derive from the evaluation of the case studies with certainty is that in each case the consults or the owners have used a very advanced technology for the time of the intervention. In other words, due to the different year of every intervention, the technology differs from case to case and so that cannot be evaluated. The fact that is worth mentioning, though, is that due to technological fiver, especially in the solar sector, new generations of solar technology can imitate color and surface structure of nearly any construction material without losing in efficiency, or even with higher performance than before.

There are different techniques for different solutions dipending the end result. For example, there are variants forming the layers in anlaminated photovoltaic module with optic filters (Figure 40)

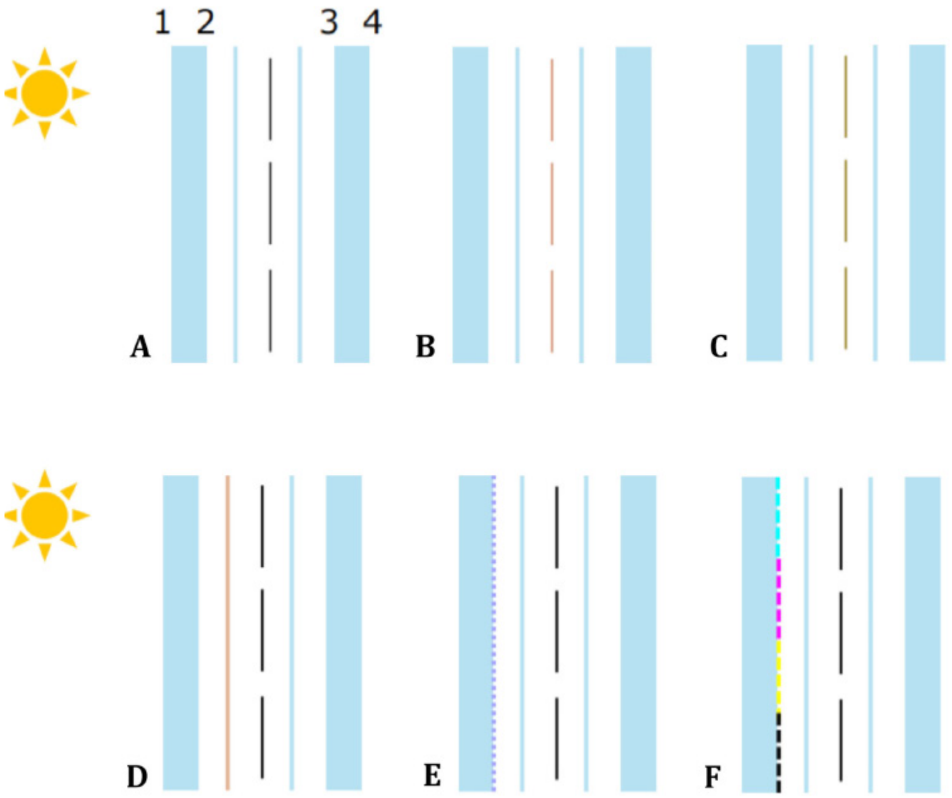


Figure (40) : Different possibilities with optic filters : A: glass/foil/pv/foil/glass, B: glass/foil/colored transparent pv/foil/glass, C: glass/foil/marble effect opac ov/foil/glass, D: glass/white foil/colored transparent pv/foil/glass, E: color coated glass/foil/pv/foil/glass, F:pattern coated glass/foil/pv/foil/glass

6.3. Evaluation criteria

As criterion is defined “ a standard or principle by which something is judged, or with the help of which a decision is made ”(https://www.oxfordlearnersdictionaries.com). In addition, from literature research was found that similar technical projects, which were focused more on the photovoltaic module construction, propose different criteria divided into two groups, objective and subjective (SURiHIB project, http://www.ccem.ch). The first group, the objective, consisted of: being parallel with the building surface, respecting the lines, shaping with the proportions to avoid uneven solar installation, grouping for optimum integration, precision of connecting elements and visibility from other buildings or from the streets. The other group, the subjective, consisted of: covering the construction surface, sizing, application, multifunctionality and aesthetics. Thus the evaluation criteria of the reference cases are going to follow the subjective and objective division.

Figure(41) : Bird-eye view of the Ca’S. Orsola (left), Bird-eye view of the Bethesda Methodist Church (right) https://www.google.com/maps

Figure (42) : St. Silas Church https://www.saint-silas.org.uk/ (left), Roman Catholic Parish St Peter and Paul Church” in Switzerland, (right)

6.3.1. Objective Criteria

As objective criteria considered, based on SURiHIB project : being parallel with the building surface, respecting the lines, shaping with the proportions to avoid uneven solar installation, grouping for optimum integration, precision of connecting elements, and the visibility from other buildings or from the streets.

Regarding how the application is respecting the lines of the building and the proportions between the covered or replaced material and the photovoltaic module, these are two criteria that are different in each case and thus each case should be evaluated separately.

In addition, the criteria of grouping and precision cannot be used in these reference cases. That is because in each case the modules are in groups in order to gather all the cables and fixings to the inverter, and the precision should exist by rule. However, these criteria are very important for cases that are not yet realized, such as the study case which is going to analyzed in the next Chapters, and should be included in the decision making.

About the integration degree; in other words, if the integration is at the same level as the surface in which they are mountained, determine the visibility of the module structure itself. Sometimes, to succeed maximum solar gains, the modules should be placed in a slope, even if the building of the applications does not have one. This creates new surfaces that do not follow the architectural style and guidelines of the heritage building, which results to alienate the photovoltaic application and eventually rejecting it (Figure 47). One example of non-integrated solar technology is the case of the “Academy Building Alter Kiosterhof” in Germany (Hermannsdörfer & Rüb, 2005), in which solar panels have been installed at an angle in the staircase of the building, providing both light and shade to the space below.

The visual criteria are those which make the highest impact to the public opinion based on literature research and reference studies. If the authority and the public opinion agree to change or not. The criteria that define this category are the visibility from different angles, the adaptability of the color to the original material which is replaced by the module, the module’s surface structure, and the extensiveness, grouping and integration degree of the module application.

Firstly, the visibility or invisibility from important viewports in the city grid, like the view from the street, or from neighbor buildings, or even from higher roof or landscape, is one of the criteria. In most cases, the visibility of the modules was disregarded by camouflaging them by changing the color, as it is going to be explained later. However, in other cases the most important visibility factor was the street view, since these cases where in historic dense city centers and the authorities were interested only for the uniform face of the street. In the case of “Ca’S. Orsola”, in Treviso of Italy , and in “Bethesda Methodist Church”, in Cheltenham of England (Figure 41), the modules were placed some meters from the street-view-edge in order not to be visible from the street level. However, the modules where still visible from higher neighbor buildings and google map top view.

Equally, the visual aspect of color adaptability is one of the most important factors for choosing a photovoltaic module, especially in the heritage cases. The shade of the module, which is going to replace visually or literally the original material, defines one part of the application realization in most of the situations. In the majority of the cases, the consultants tried to match the color of the photovoltaic module with the original materials. For example, in the case of “St. Silas Church” in England, which was one of the first heritage buildings in the UK that embraced the solar modules, special designed modules were installed to match the color of the slate in the rest of the roof (Figure 42). At the same time, in “Roman Catholic Parish St Peter and Paul

Figure (43) : The Rural House, side and top view (http://www.issol.eu/solarterra/)

Figure (44): Solar Quotation Board (Hermannsdörfer & Rüb, 2005)

Figure (45): Chalet in Innerkirchen https://www.sunstyle.com

Figure (46): Neo-Gothic Church https://www.sunstyle.com

Figure (47) : “Academy Building Alter Kiosterhof (Hermannsdörfer & Rüb, 2005)

Church” in Switzerland, the whole roof slope was covered with photovoltaic modules, which replaced the old roof tiles, without modifying the global image and perception of the church within the landscape (Figure 42). In the above cases the color that was chosen was grayish-blue in contradiction with the next cases in which the terracotta color was chosen. The case of “Rural House” in France is considered “state of the art” heritage case study (Figure 43). The reason behind it is the fact that the company ISSOL designed a module especially to imitate the terracotta color in module with high efficiency and acceptable from heritage authorities . Furthermore, in the case of “Solar Quotation Board” at City Wall Marbach am Neckar in Germany (Hermannsdörfer & Rüb, 2005), thin-film photovoltaic modules were mounted onto the historical city wall and, to ensure optical harmony with the natural stone of it, the structure and colors of the wall were adopted as background design for the modules (Figure 44) .

By the same token, the structure of the surface also tries to emulate the surface structure of the replaced or neighbor material. This can be divide into two sections, the structure of the whole surface, like the fish-scale pattern mentioned before, or the outer surface of the photovoltaic module itself. Typically, the consultant experts advise the use of matt finish and frameless module in order to avoid light reflections to the surroundings and not to modify the global image and perception of the cases within the landscape, especially when the cases are in dense urban environments. Cases with this decision were the “Rural House” in France, and the “Roman Catholic Parish St Peter and Paul Church” in Switzerland, mentioned above. Conversely, high reflectivity modules where chosen for cases in remote districts since do not affect the global image. Examples of these modules are the “Chalet in Innerkirchen” in Belgium (Figure 45), the “Church in the Strand Municipality” (Figure 39), and the ”Neo-Gothic Church” in Norway (Figure 46) .

Last but not least, the extension of the application and the grouping of modules define the optical effect in the public eye. High percentage of coverage of photovoltaics and grouping the modules, provide the sense of unity in the eye (Figure 38), like the case of “Roman Catholic Parish St Petr and Paul” in Switzerland, while a low percentage of coverage makes the application visible (Figure 42), like the “Reformierte Kirche” in Vienna, regardless of the color difference.

6.3.2. Subjective Criteria

The subjective evaluation criteria, consisted of: covering the construction surface, sizing, application, multifunctionality and aesthetics. These criteria are called subjective because there is no correct answer and the final evaluation upon these is made based on the general opinion. Of course there are positive, negative and neutral position to these matters, but the quality of the answers I based upon personal taste and experience. Usually, questionnaires are being conducted in order to clarify what is the general opinion and the acceptable from the local community. These are the acceptability studies that are going to be explained in Chapter 9.

6.4. Photovoltaic application process

The application of photovoltaic technology in heritage buildings is considered difficult or relatively impossible, due to several regulations and guidelines in the heritage preservation context. However, instead of considering building integrated photovoltaic technology (BIPV) as a technical constraint for designers, there are several proposals approaching the BIPV solutions as "staple" for architectural renewable projects. These approaches provide extra value to the already important historic structures, and also a motivation for a large-scale photovoltaic integration into urban renewable procedures.

Renovation scenarios with BIPV in a building

A first approach to this issue is the substitute of construction elements by photovoltaic components, which have an appropriate response to the requirements of the overall design (Aguacil, Lufkin, & Rey, 2016). Important to recall that, this approach is combining the application of the photovoltaic technology in the renovation framework of a heritage building. In this research, a multiple criteria evaluation of the proposed design scenarios allowed comparing different strategies. This approach illustrated the effect of the architectural design decisions on the finishing performance and appearance with respect to the building.

The proposed methodology consisted of, firstly, selecting a heritage building and detailing it to the point of analysis of the current status of the envelope. The selected building is a modernist example in Switzerland (Figure 48). Then, the process continued with forming the architectural renewal scenarios. These consist of : E0-Current status (reflecting the actual situation), S0-Baseline (aims achieving at least the current legal requirements of SIA 2009), S1-Conservation (aims to maintain the expression of the building while improving its energy performance), S2-Renovation (aims to maintain the general expressive lines while reaching high energy performance), S3-Transformation (aims best energy performance with aesthetic coherence to the whole building) (Aguacil et al., 2016).

The conclusions to this research indicate that, energy renovation projects without the application of renewable energy sources, and BIPV in particular, are no longer feasible option if it is to achieve the "Energy Strategy 2050". In addition, by implementing passive and active strategies and renewable energy systems, it was achieved 89 percent of total energy savings. Despite that, there is no mention of guidelines that had to be followed from local authorities, but only the possible application scenarios presented in graphs (Figures 49 & 50). (Aguacil et al., 2016)

Temporary structures

In like manner, another research of photovoltaic application, promotes that photovoltaic systems can be spread into three categories based on their position to a building, which is an energy recipient: Building attached photovoltaics systems (BAPV) (integrated into the building envelope system), Building-integrated photovoltaics systems (BIPV) (subspecies which are Building-integrated solar thermal systems (BIST) and Building-integrated hybrid systems (BIPVT)), and Building-independent temporary

Figure (48): Building image (current status)

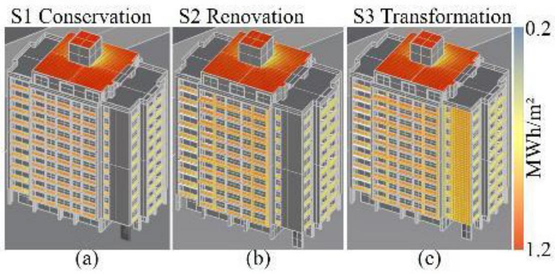


Figure (49) : Annual irradiation level for each scenario.

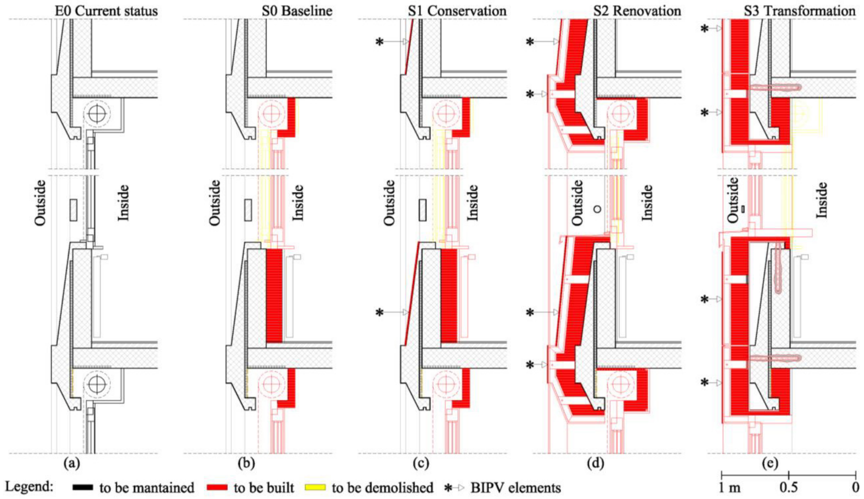


Figure (50): Renovation strategies for each scenario. Detailed section of the main façade

photovoltaics construction (BITPVC) (Murgul V., 2014).

These three categories are proposed based on finding upon solar energy technologies in the heritage neighborhood of a northern city, for example Saint-Petersburg. This case is interesting because, on account on the main concerns of security regulations for historic buildings of St. Petersburg, in most cases, changes in exterior facades are not allowed, with only exception the first floor. In addition, it is impossible to change the composition of exterior slope of the roof, and losses can occur in the shade since St. Petersburg described excessive density of urban development. For all these reasons, the author proposes additional energy supply systems, based on solar energy in the extent of temporary structures, which will be potentially separated from the main core of the building. Furthermore, the dynamically changed conditions in an urban environment can support this solution system, allowing the mobility and flexibility to the energy system to meet changing energy social demands (Murgul V., 2014).

With this in mind, the authors presented the glass as a "forgiving" material for working in the heritage environment, since it's not visually dominant and it's capable of reflecting and remain itself. In addition, if the new elements are detachable, they can be separated from the building at any time, leaving the original integrity untouched (Murgul V., 2014).

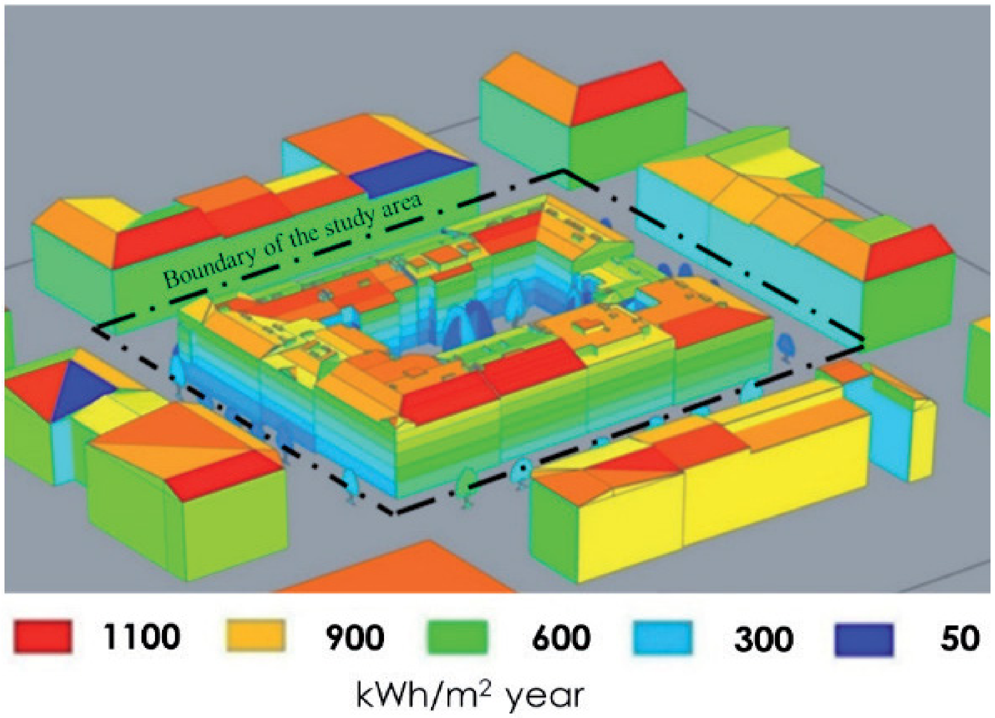


Figure (51): The annual solar irradiation map and relative PV potential of the building block based on the selected irradiation thresholds in the Vinohrady area.

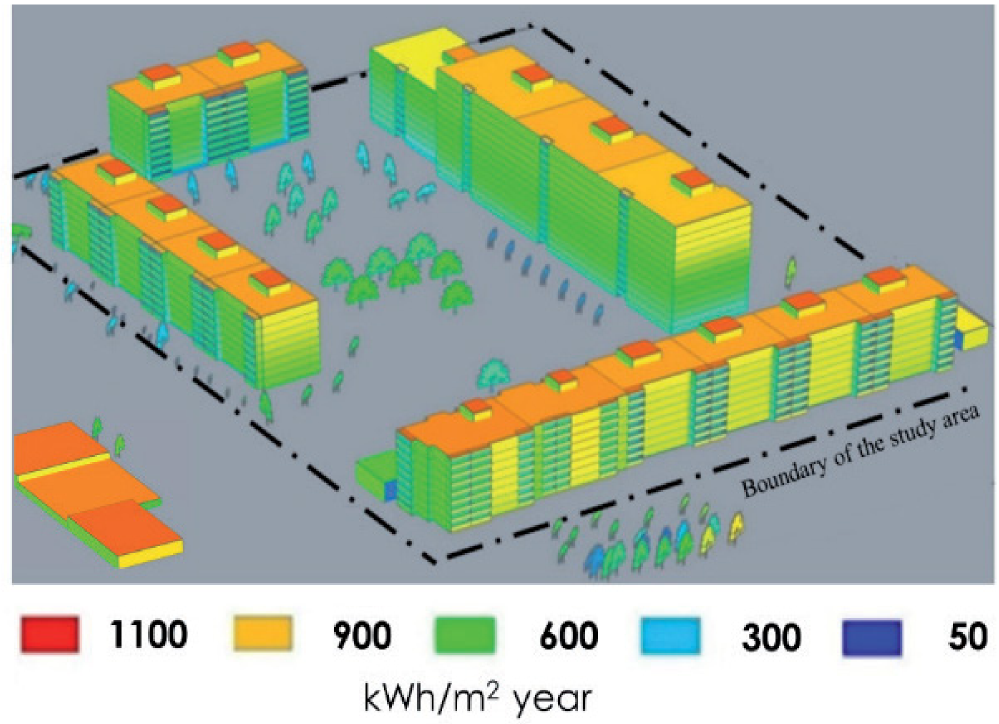


Figure (52): The annual solar irradiation map and relative PV potential of the building block based on the selected irradiation thresholds in the Jizni Mesto area.

Solar photovoltaic potential in a block of buildings

A second approach that was found through literature searching was a research upon solar photovoltaic potential in the city of Prague (Skandalos, Tywoniak, & Maierova, 2019). Prague is the capital and largest city in Czech Republic located in the north-west of the country. Its climate is counted as semi-continental, characterized by large seasonal temperature differences. The methodology that was followed here was to choose building blocks in two urban areas in the same city with different characteristics: a building block built in the 20th century, constituted of residential buildings, in a high dense area in the city center with high architectural and cultural value (Figure 51), and in a suburban area built in the 1970s, a building block consisted of high-rise prefabricated buildings (Figure 52). The first block is featured by sloped roofs in different shapes and heights and the second one by its simple shape, flat roofs, large vertical facades with balconies and better insulation compared to the first block of choice ndalos (Skandalos et al., 2019).The choice of two different locations in the same city increased by the fact that, the location of the energy source occurs with the location of the energy use. As a consequence, the produced electricity can be used immediately for each building's needs, but at the same time create an electrical grid in the building block itself.

The conclusions to this research were calculated by the annual solar irradiation maps in the two areas. In the first building block, Vinohrady area, the facades found to receive a remarcably lower level of radiation, which is explained from the mutual shading effects from the high-density urban environment in the city center, especially for the lower part of the buildings. On the other hand, in the other group, Jizni Mesto area ,the maximum potential was slightly reduced (around 10 %) compared to Vinohrady area. This agrees with the flat roof on top of the buildings, followed by the south-facing facades and a diffused PV integration on the vertical facades. Furthermore, solar blockade was found to be much lower owning to the less dense urban environment of the location. Generally, according to the selected radiation lower limits, the analysis revealed almost a 3 times higher potential in Jizni Mesto compared to the Vinohrady area. As expected, most of the potential is related to the roofs, while the facades suffer more of a shadowing effect caused by the surroundings. The phenomenon is more intense in the Vinohrady area, where only 13 % of the PV potential is connected with the facades, when the additional contribution in Jizni Mesto is approaching 50 % (Skandalos et al., 2019). The latter is revealing that, even in areas with a heritage value, the application of solar energy is still feasible in need of equilibrating the local electricity needs.

6.4. Conclusions of the case studies analysis.

The value of a conservation and renovation project for a heritage case is based on the ability to come to an understanding between the requirements of current legislation on static safety, accessibility, compatibility and energy savings set against the architectural and material characteristics of buildings, which are designed and constructed according with other criteria (Polo López & Frontini, SUPSI). These days, many solar technologies available on the market, are specially designed for this type of integration, reducing the impact on the building at the same time. In any case, materials are being developed in order to reduce visual impact, especially into buildings of great architectural value. The important is that, the designer comprehend the diverse qualities and the special features of every product, in terms of performance and aesthetics evenly, in order to increase the number of potential proposals.

To sum up the evaluation to the study cases, these are the main key points that this research is going to focus on.

Every project is unique due to different landscape, circumstances, scenario of integration and needs of the building itself. Every case is a living organism in a specific urban environment with unique character and so every change should be planned carefully in order to preserve the architectural probity of the history. Furthermore, it appears that the most successful cases were those in which the photovoltaic modules were immitating the original material. Only in cases that the community and the owner would like to demonstrate the new technology on a heritage building and only then the modules should be visible in every aspect, like information boards.

What is more, it appeared that most of the cases were in the Northern Europe and it can be assumed that follows the economic and technological fluency, in contradiction to the southern Europe that they lack of funds. On top of that, the regulations are more outdated in the south, rather than in the north of Europe and often deny the possibility of solar application in historic urban environments.

The typology of the buildings like churches, due to form, should lead the application movement because of advantageous orientation and building height. Movements like the Eco-Church should set an example of how history can be treated with new means. In addition, the residential typology of farm houses and remote district cottages should follow the solar example because of existing in low density urban environment.

All things considered, the architectural character of the building and the historical surroundings should be preserved. This is possible when by planning the solar application, the lines are respected, the modules are grouped, and the color is adapted to replaced material in the area of application. These should be elements that every solar consultant should know in order to apply smartly and without the denial of the heritage authorities.

Summing up all the different reference case studies in this chapter it appears that both objective and subjective criteria are important for the final result. Even if all objective criteria are in order, there would be always an extra opinion upon a subjective one, such as the aesthetics. Nevertheless, in the end, if it is approved by local authorities then could be realized even if some of the criteria are not corresponding with the objective ones. The reason behind it is that, in some countries, and thus authorities, some criteria are considered more valuable than others, such as the visibility aspects, and that is why two similar cases in two different countries, with the same characteristics and architectural typology are treated differently. Recapitalizing, it is recommended a certain framework to be formed from the European Union and UNESCO in order a similar path to exist in every country's legislation system and then to be translated based on the culture and tradition of each one.

7. Case Study in Greece

Figure (53): Cart-postal picturing the city centre of Florina in 1914-18 (www.florinapast.gr)

Figure (54): View from the street in the historical centre of Florina showing two types of heritage structures: the yellow is considered neoclassical and the white one is influenced by the Turkish Occupation (https://www.dpgr.gr/forum)

7.1. Introduction

The method that helps to prove the feasibility of the heritage retrofit, specifically the application of photovoltaic technology, is a specific case study research on a listed building in Greece. This is considered the best approach to integrate all the findings from literature research. A real case study in a physical living environment is going to be the subject of the case, without really executing the design in practice. That is because the adaptability of the final product is going to be tested not only with the energy data production and detail assessment, but also to be evaluated upon architectural integrity and public's acceptance.

7.2. Choice of case study building

The chosen building is called "Diethnes" (International) due to its former use as a hotel with this name. It is a 1920s structure and follows the Greek eclectic architectural movement, and especially the neoclassic form. The privately-owned building is a true representative of the movement in the area of western Macedonia, in Greece, in the city of Florina, and it is one of the listed buildings in the area (Greek Governmental Decree, N.1460/50). At first, it is being presented and analyzed through historic sources, designs and testimonies since it is a heritage building. The following subjects are going to be the reason behind the importance of the case study. In addition, the building was surveyed and thus it will also be presented as testimonial from the writer's point of view. The different approaches could show the change of perspective on a heritage building, which is something that is common also when solar energy is approached by people with different backgrounds.

The building, for this case study, is chosen by the writer's experience and witness to the specific building environment. Initially, there was personal enthusiasm about retrofitting a heritage building that is so important for the local community in a city of the north-western Greece. However, under an objective perspective, the architectural movement, that this building is representing, is very broadly spread to almost everywhere in the Greek building environment. Moreover, after researching this specific architectural movement, there are findings that indicate the importance of the movement in Europe and especially in central and north-east site(Z.P.Christina,2003). This particular movement, the neoclassic architecture, was a movement that won the ground in different European countries for different reasons. Although the circumstances were different, the common element was the neoclassic architecture that was used in order to show magnificence with an approach to a glorious past, that of the Ancient Greece.

7.3. Building's architecture, services and installations

Hotel "International

- Location : Florina, North-western Macedonia, Greece
- Address : Naousis & Prespon
- First Owner : Simou Brothers
- Architect : Meletiou Aristotle
- Year of Construction : 1924
- Use: Market and Hotel

Original Drawings: Colored paper 105 x 39 cm, it contains three drawings : layout of underground and ground floor, layout of first floor, view from the Dellaporta street (scale 1:100) (Figure 55).

The building's entrance façade is facing south-west and it is placed in an angle with the main street. It is built on the construction line and it has three uncovered facades. It occupies the whole area of the polygon plot and skylight duct was created inside of the plot and in contact with the neighboring plot. Why is this or otherwise , only state that the historical drawings do not match the current building and the reason for this is not known. There are many differences between the original drawings, which exist in the archive of the local authorities from the first attempt of the architect, and the constructed building itself, and especially in the views. It is important that the draw-

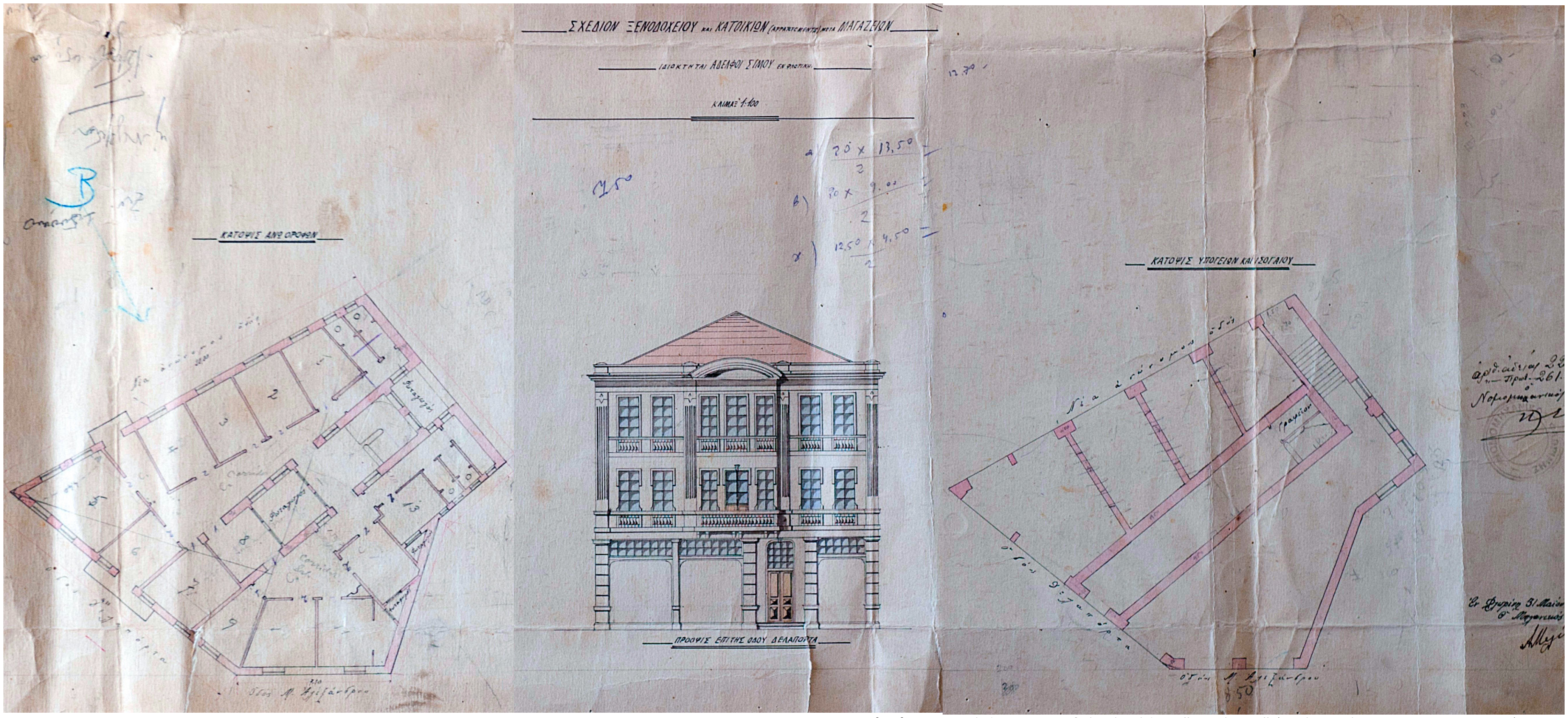


Figure (55): Original drawings of the building "Diethnes" (Urban Planning Department)

ings are shown that the building was designed to have three floors but only two were realized, the ground and the first floors.

The morphology of the building is described by the simplicity of the synthesis, while the symmetrical guidelines from the first floor do not exactly correspond with the openings of the ground floor. The frames (pseudo-parastas), which are surrounding the openings in the ground floor, determine the base of the building, while the two-floor-height ornamental columns (pseudo-columns) with their vertical ribs are unify the two floors and they organize panels where the openings stand. The central zone of the view slightly protrudes, and it bears a curved ending and a balcony with terracotta pillars (balustrades) on the first floor.

The above elements are part of the final drawings that unfortunately has not been saved. More specifically the weakness of lack of symmetry on the first drawing was the reason why was not realized.

The uncovered facades are organized with vertical columns of openings that are surrounded by frames following the neoclassical architecture. The ribbed columns of the ground floor continue to the second floor, even there is a distinctive line between the two floors, where they are in a better condition and with a Doric crown (pseudo-crown). There are equal horizontal joints which run across the surface of the floor, while ornamental frames with built parapet are the ending of the building. The openings of the first floor that cover the whole zone every time, are closing with wooden framed glass doors, while in the first floor there are small window-doors with small balconies. The simple geometrical frames are ornamenting these openings, while the balconies have elaborately metal railing.

The zone of the hotel's entry is underlined with the recess in the center and the creation of an alcove, which is maintained on the floor with the addition of a large balcony. In the slightly curved lintel of the frame, there is an ornamental element with a wall watch in it. Left and right of the ornament, there is the epigraphy "Hotel "Diethnes" (Hotel International). The vertical axis of the entry is underline with the projection of balcony in the attic of the building, which ends in a triangle pediment. which has the epigraphy of the year of construction of the building: 1924.

The attic seems to be held by helical braces, while there are ornamental columns that frame the recess of the view and they continue to the ornamental pots. In the base of the parapet exists a small canal for the rain and snow to run of the facade. The faces of the building are complete with the special treatment of the corners of the plot, where the building has a curved zone in the south-west and north face while in south-west and east site is a clear angle.

Generally, the structure is 14.30 m x 20.00 m x 11.00 m, counting the triangle pediment. and it is covered with wooden roof. The foundations of the building are constructed with stones and bricks 50 cm and 37 cm from the cell of the ground floor and 25 cm from the bearing walls of the inside, while the rest of the walls are 11 cm in thickness. At the same time, metal beams that are supported by the bearing walls of the structure and brick columns, are supporting the walls of the first floor which makes the two floors to differ in layout. In addition, the colored tiles in the entry and the wooden doors and windows inside and out, give an interesting scene to the building.

The building used to be a hotel with stores on the ground floor. In the ground floor there are stores and quite central of the south-west view (from Naousis street) there is the door of the hotel. Thirteen rooms exist and are placed in the perimeter, while the

Figure (56): Building "Diethnes" then and now (https://www.dpgr.gr/forum)

flow to them is done through two elongated corridors that they are close to parallel with the rooms and they are lighted by the skylight duct of the middle zone. There ends the staircase with which the floors are communicating. There are four common sanitary rooms and a shower room. The room of the reception of the hotel exists in a small space between the staircase flatten in the entrance.

Due to the fact that the building has almost the same heights as the surrounding buildings, apart from some exceptions, for example in the south-west of the location, it has solar radiation for the most part of the day. Specifically, the roof has daylight as the sun shines and the south-west façade has sunlight in the afternoon. Throughout the day there is diffused light. For these reasons, it is suitable to place photovoltaic modules in an angular position in all surfaces of the roof, following always the existing slope, and in a vertical position in the south-west and south-east façade of the building.

7.4. History

7.4.1. International background of Neoclassic movement

The manifesto of Le Corbusier and Gropius and their ideas of an international architectural wave, gained ground in Greece and as a result, the congress of modern architecture, known as CIAM, was born (https://www.open.edu) . However, the ideas of modernism and the simplicity, lead into incapacity of the movement to express character of authority on the buildings in 1930s (Birēs & Kardamitsē-Adamē, 2004). At the same time, the rebirth of a more expressive and based on the ancient Greek history architectural movement, and the birth of the term “New Tradition”, were the elements which lead to the creation of the new architectural movement in 1929. In addition, the Greek population after great fights and hundreds of years under the pressure of conqueror, could not realize the development of the rest of the world and thus modernism could not win the vast population. Within this frame, a monumental, national style was born with the term of “neoclassic palaces for the people” in Stalin’s Russia, while in France the same style was used for showing the national glory of the 3rd Democracy. Simultaneously the same neoclassic morphology was used in Germany in order to show the sublime of the Nazi regime (Z.P.Christina,2003) , and at the same time in England it is called “Greek Revival” (X. Pappa, 2017) . In the second half of the 18th century, the descriptions and illustrations published by foreign travelers led to increased European interest in Greek antiques (Birēs & Kardamitsē-Adamē, 2004).

In contrary to the general belief, Neoclassicism did not make its first appearance in Greece with the arrival of the Bavarians. The construction of the first buildings in a neoclassical style began as early as 1815, when the British captured Corfu and thus completed their occupation of the Ionian islands (Birēs & Kardamitsē-Adamē, 2004). The French expression of the Neoclassical movement was usually used in the beginning of the era, in the latest of the Ottomanic Period and in the beginning of the newly constituted Greek State, in public buildings like schools and town halls. This form of the movement has gained ground in Istanbul and then has become the main form of the movement in cities still under Ottoman sovereignty especially in the North, like the city of Thessaloniki. The approval of the plans from the ”commission of 1860” changed the old city of Athens with the ottomanic style, and aimed to a new modern environment, with a European sense. With the new king of Greece, Otto from Bavaria, Athens got the German form of the neoclassic style. This style was expressing the monumental glory of the royal institution.

The new element in the architecture of that period (1833) was the intention to develop a more formal view to the face of the street, which constituted the front yard. The mandatory change of the building plots into rectangle, led to volumes compatible with the neoclassic movement. There were no specifics guidelines to the formation of that architectural movement, except of the volume of the structure which led to the orderliness of the city's’ image. The architect or the engineer with the guidance of the owner was free to form the typology and morphology of the buildings, based upon the architectural experience and vision. (Monioudi-Gavala, 2016)

Within the climate of nineteenth-century liberalism, the acquisition of an urban character, which is considered the most important achievement of the transformation of Greek society by Bires M. (2014), should have been strongly projected, in contrast with the underdevelopment and marginalization of the years of subjection, oppression and enslavement. In a way, the “national” architecture changed the traditional forms of the past, which were linked with the years of subjugation, through new associations of ideas identified with individual dignity and collective modernization. Its morphology provided the figurative codes through which the symbolic view of the new urban life could be expressed (Birēs & Kardamitsē-Adamē, 2004).

Figure (57): View from the street in the historical centre of Florina showing buildings influenced by the Turkish Occupation (https://www.dpgr.gr/forum)

7.4.2. Typological Exploration

The Neocalssism is defined by straight lines, bare surfaces and the white color in the facade. The straight-line rule only is corrupted by the appearance of circle shapes in the corners, lofts and niches. The light feeling, of the ornaments comes in contradiction with the volume of the structure. In addition, the existence of underground spaces gives to the movement a romantic touch and love for the ruins (X. Pappa, 2017)

Based on the structure of the movement, the building’s volume should appear as one volume as compound as possible and to include straight surfaces. The columns, which appear in the facades, do not have a repousse feeling, but mostly become one with the building and form a column array, just like in the ancient temples. The orna-

Figure (58): View from the street in the historical centre of Florina showing neoclassic buildings (https://www.dpgr.gr/forum)

mental elements usually appear in a different layer and closer to the surface between the columns. The surface between the columns, usually, is divided to parts in order to appear organized. The color scheme varies from light to more darker hue and its based to the colors of the Renaissance, and in addition, the same guideline is used to eaves and walls. (X. Pappa, 2017)

7.4.2.1. Synthetic principles

Initially, the style was applied to official and branded public buildings, but also to large mansion houses. These principles have provided a set of typical forms, standardized and codified, easily identifiable and understandable. The synthetic principles regarding the function and form of the neoclassical building are detailed as follows (Cremezi A.,2009).

To begin with, the structural system used is that of a beam on a pole, in other words, vertical portions of stone-built walls on which the horizontal wooden floors and the tiled roof are, more rarely and depending on the area, the horizontal parapet. Often in the underground there are domes and arches. In addition, the layout of the top and bottom are geometrically defined with guide shafts for walling, the location of the openings, the layout of the individual elements (balconies- pediments, etc.)

As for the exterior of the building, the views are divided by height into a base, trunk and roof. The main face is symmetrical in width, often (consisting of) a central part that is slightly protruding to its sides and is crowned, where appropriate, with a pediment with which the vertical axis of symmetry is strongly emphasized. On top of the axis, the elevated entrance door with the marble steps leading to it and the central marble balcony on the floor. Furthermore, the layout of the openings and elevators on vertical axes, as well as the central pediment that surrounds the whole, highlight the vertical direction, while repeating windows that are rhythmically listed as well as other elements of the building's trunk, such as the cornice, small perimeter bands indicating the position of the buttons, decorative strips, help to emphasize the horizontal direction.

The Classical movement can be found with small alterations all over the Greek peninsula. In contrast with the situation in the islands, the type of buildings found in the rest of Greece, from north, like Macedonia and Thrace, to south, like the Peloponnese, is quite similar to another, exhibiting only slight differences between them. They are types that, according to Aristotle Zachos, share a common origin in the Byzantine house. These large two or three story archontika (mansions) had stone ground floors and lighter timber-and-brick structures on the upper stories. This arrangement, not only made sense structurally, but also gave craftsman greater flexibility, allowing them to create more and larger openings, to use projecting timber structures (sachnisia) and large balconies (chayatia), forms encountered throughout the entire Balkans (Birēs & Kardamitsē-Adamē, 2004).

The architectural view of Florina in the last period of the Turkish occupation in the area (1900-1910), consisted of wooden buildings with Balkan style, which most of them were in sparsely populated areas. Simultaneously, in the biggest road of the city, which was started to form, there were built continuous structures with ground floors, which were used as stores, and with two upper floors with mixed uses. This typology was the first in the area. At the same time, public buildings were the landmarks of the city (Z.P.Christina,2003).

The city as it incorporates with the rest of the northern Greek regions, started to flourish through the social and political calls of the time. New public buildings were created to serve the people, while older structures were starting to be used, as in the Turkish occupation period. The Turkish houses due to the side of them were used for the public. New schools, court of justice, banks, hospitals and other landmarks were being constructed, resulting from the rising population and the development of the small city to a great trading center of that time. Because of the last and the nature that surrounds the city, Florina was becoming a great tourist destination of the area. For that reason, motels and hotels were starting to be built in the city's grid, in order to host more and more people. In the beginning, the only way for a tourist to stay in the city was to rent a room in a house for a few days or some public houses that they didn't follow any sanitary regulations (Z.P.Christina,2003).

Furthermore, at the same time, the construction of ground floor gallery was constructed and the typology of two floor gallery was introduced not long after. In addition, the uncovered area is getting smaller, the yards are being occupied by buildings, and the air duct and skylight were being embodied to the buildings (Z.P.Christina,2003).

The roof of the buildings of Florina continued throughout the Middle War period to be formed with wooden structure, independently of the construction technology at that time, the building materials and the architectural expression. The dimensions of the individual wooden elements depended only on the size of the building. However, the angle of the roof pitch according to the 1929 GCG (General Construction

Figure (59): Colorful facades is street view, Florina, Greece, (http://kparlapani.blogspot.com/2010/01/blog-post_3651.html)

Figure (60): Greek neighborhoud "Varosi", Florina, Greece, (http://kparlapani.blogspot.com/2010/01/blog-post_3651.html)

Guideline) must not exceed 40 degrees with the flat surface. The covering of the roof is originally made with tiles constructed from craftsmen from the region, while the French tiles are the cover of the roof after 1920. Rarely, there are cases where tiled tiles form "fish" skin type to cover the roof and form higher pitched roofs (Z.P.Christina,2003).

7.4.2.2. Repousse Façades

In the Neoclassical style, buildings belong to the aesthetic category of "plastic", characterized by order, regularity and abstract geometry. All of the individual elements are tied together as an organic form. They are intended for a specific location and are appropriately designed for it. They are not parts of the whole that can be moved. Generally, the form of the building is "closed", integrated and consolidated and cannot accept additions without effect on the general composition (Z.P.Christina,2003).

The façade of the Neoclassical style consists of plane surfaces, but mostly ceramic decorative elements. Ceramic caps, ceramic railing and pots adorn the facades of the eclectic buildings of Florina, morphological elements reproduced in special workshops. Originally, the capitals are Doric, and later they are gradually replaced by stylized Doric capitals formed in the coating to further simplify them, until they are abolished completely in the 1930s. In the ceramic decoration of the facades, flower decorations are added in the coronation of the buildings in the 1920s. Ceramic decorations, like pots, in the coronation of buildings emphasize the mood for decoration, while the same elements are also included in the decoration of the frames.

The pseudo-columns consist of three parts, trunk, base and capital, void inside that fit into each other. On the column, a metallic blade is fastened by coating, which is welded to the vertical axial armature, runs along the parapet and by adding a series of bricks then forms the railing (Z.P.Christina,2003). The weakness of the construction lies in the fact that the ceramic railing merely connected on the support surface and can easily be detached and collapsed.

7.4.2.3. Color of Façades

Surveys on the color organization of the newer monuments in Greece are very limited and fragmentary without providing significant documentation on the subject. Color research, particularly on the exterior surfaces of buildings, is particularly difficult, where is wear off and teared due to lack of maintenance and the age of the building or laminated layers in trials of renovation. But, it is possible to investigate the color layers which were applied in building, but it is very specialized and time-consuming, as it is necessary to test sections at various points of the façade, both in the background and in the decoration, and also perform stratigraphic analysis. However, an initial approach to this issue could be possible through research of building guideline and archive material of designing offices. In particular, building regulations lay down restrictions on the use of colors on the facades of buildings, while watercolors of

Figure (61): Blue and white color scheme of greek properties during Turkish Ocupation. (https://www.dpgr.gr/forum)

façade design sketches are an illustration of these relevant provisions, and consequently a first documentation of the color organization of such buildings.

According to the Decree in the newly established Greek state in 1865 (Greek Governmental Decree, N. 19/15.5.1835, 14),"it is forbidden to use in the exterior and interior of the building, all bright colors, like red, deep yellow and white, as well as the oil-paints and varnishes as harmful to health". However, the limitations of the Decree contradict the color identity of Ancient Greek classicism, as first extensive publications circulated during the same period which were dealing with the subject of the multicoloring of Greek antiquities. Through the Decree, there was a desire to use a cold range of colors, such as gray, gray-blue and blue . However, M. Bires is considering that the limited use of these colors in Athenian classicism, is dominated by the soft occlusions of the ocher yellow, which predominantly deviated from the warm, earthy tones, or even the lightest on the wall surfaces, while the architectural elements, which have a prime significance for the style, are colored in white (Birēs & Kardamitsē-Adamē, 2004). At the same time, the frieze that runs in the shadow of roof edge, is usually painted in the tone of gray-blue or , in the later period, it does not differ in color from the other surfaces. However, in the second half of the 19th century, a shade of terracotta is used in the set of outer faces and the most common in the colors of the depth (galleries, ornamental niches top), combined with open ocher yellow gradients. The color image is complemented by window frames painted in tones of gray-brown, blue or green (Z.P.Christina,2003).

In Turkish-occupied northern Greece, at the same time, the prohibition of the use of red color in non-Muslim districts seemed to be valid, as documented in Florina, from a first investigation of the coloring of exterior facades of non-Ottoman buildings. More specifically, the use of the blue aquamarine with lime is the first painting in the

Figure (62): Street view, Google maps, Before and after renovation of the building.

dwellings of the "Varosi" neighborhood (Figure 60). More specifically, after the second half of the 19th century, this color spreaded across the surface of the faces and seemed to continue in the decoration (Z.P.Christina,2003). For example, based on a photograph from 1910, Z.P. Christina stated that: “The house built in 1902, is painted with a light gray-blue tones, while the ceramic domes of the pseudo-columns remain in their natural tone, as the surfaces were formed with decorative plinth”. However, this is not visible in the recent view of the buildings, since it was repainted to match the colors of the surroundings. Meanwhile, a recent renovation of neighbor building, was painted in the original colors keeping the character of the past with a twist of the present, which included aluminum double glazed windows in brown-wood color. (Figure 62)

The first period after the liberation of the city in 1912, is illustrated by a strong mood for free expression at all levels. There was a prohibition of red color on the exterior facades of the new buildings which are being built or the renewal of the color of the older buildings. Especially the first color of choice is a kind of terracotta, a color often found in types of Italian villa "coral terrazzo". The tones of the ocher on the exterior faces of the buildings of Florina appear to have been used around 1925. Even the tones of the ocher are the third layer of dyeing of the Turkish domination cheeses and the second for the buildings built in the first period counts the release.

However, independently of the color of choice, monochrome characterizes the surfaces of the buildings, in the effort to promote the material homogeneity and continuity of the forms, displaying its plasticity. Color variation when present is achieved only by imitation marble or the use of other materials such as stone or decorative solid brick, which have a prime position with the rhythm structure of the building (base, frames). Finally the railings are colored black while the metal entrances of the coffee shops or green ones.

Figure (63): "Aristotelous Square" by Anastasios Orfanidis, Thessaloniki, Greece (http://enplosimioseis.blogspot.com/2016/05/blog-post_12.html)

7.4.3. Hotels & Motels

The typology of the building did not change the style of it, except from the residential function which usually included a courtyard, but it changes the division of the inner space. The typology of the building was very important at the moment which it was built, and the building's style followed the dominant architectural movement in public buildings at the time.

The motels and hotels were usually two floored buildings, which were placed with the face on the central road of the city and close to the market. They were in the place of public houses (khan) at the time of the Turkish occupation. On the ground floor there were stores, traditional cafes and restaurants and the use of the hotel was expanded on the floor (Z.P.Christina,2003).

It was common that the rooms were placed side by side and faced to the street and the opening to the yard was replaced by the corridor. The sanitary rooms were common and small outside of the room zone. The reception of the hotel was very small and usually was used as a living space for the manager of it. Sometimes there were stables added but not before the first decade of 1920 (Z.P.Christina,2003).

7.5. Regulations & Guidelines of Neoclassism

The small margins of the land in Florina, which was determined by the decree of 1919 and the amendment of 1927, they have given the allowance to build small houses in the central road of the city. Until 1923, as it is mentioned by V.Tsagris, "the government did not interfere to anything except the maintenance of the building line ", until 1929 when the first National General Building Regulation Framework was settled (Z.P.Christina,2003).

In the regulations and guidelines of the first National General Building Regulation Framework, it is underlined the importance of law-guided building views in important points of cities, like in big squares, landmarks and big streets, near public buildings and monuments with special archeological and historical value, in order to maintain the high quality of architecture of the newly constructed buildings and thus the city's image. It is valuable to mention that the same guidelines of eclecticism existed in many European cities from the second half of 19th century. Specifically, it is underlined the importance of the uniform view to be imposed by Ministerial Decision. The decision was going to maintain the height of the buildings with uniform and continuous views, and in addition the use of the same architectural image of the structures. One of these cities in which the new framework was imposed was Thessaloniki, and more specifically, the Aristotelous Square (Figure 63) where the owners until now have to maintain the color and the decoration of the architectural style of these buildings which face the square and keep the condition of the buildings to maximum quality. That being said, with the same spirit, the city of Florina was keen to follow the guideline to the big streets of the city center (Z.P.Christina,2003).

The morphology of the building is described by the simplicity of the synthesis, while the symmetrical guidelines from the first floor do not exactly correspond with the openings of the ground floor. The frames (pseudo-parastas), which are surrounding the openings in the ground floor, determine the base of the building, while the two-floor-height ornamental columns (pseudo-columns) with their vertical ribs are unify the two floors and they organize panels where the openings stand. The central zone of the view slightly protrudes, and it bears a curved ending and a balcony with terracotta pillars (balustrades) on the first floor.

The above elements are part of the final drawings that unfortunately has not been saved. More specifically the weakness of lack of symmetry on the first drawing was the reason why was not realized.

The uncovered facades are organized with vertical columns of openings that are surrounded by frames following the neoclassical architecture. The ribbed columns of the ground floor continue to the second floor, even there is a distinctive line between the two floors, where they are in a better condition and with a Doric crown (pseudo-crown). There are equal horizontal joints which run across the surface of the floor, while ornamental frames with built parapet are the ending of the building. The openings of the first floor that cover the whole zone every time, are closing with wooden framed glass doors, while in the first floor there are small window-doors with small balconies. The simple geometrical frames are ornamenting these openings, while the balconies have elaborately metal railing.

The zone of the hotel's entry is underlined with the recess in the center and the creation of an alcove, which is maintained on the floor with the addition of a large balcony. In the slightly curved lintel of the frame, there is an ornamental element with a wall watch in it. Left and right of the ornament, there is the epigraphy "Hotel "Diethnes" (Hotel International). The vertical axis of the entry is underline with the projection of balcony in the attic of the building, which ends in a triangle pediment. which has the epigraphy of the year of construction of the building: 1924.

The attic seems to be held by helical braces, while there are ornamental columns that frame the recess of the view and they continue to the ornamental pots. In the base of the parapet exists a small canal for the rain and snow to run of the facade. The faces of the building are complete with the special treatment of the corners of the plot, where the building has a curved zone in the south-west and north face while in south-west and east site is a clear angle.

Generally, the structure is 14.30 m x 20.00 m x 11.00 m, counting the triangle pediment. and it is covered with wooden roof. The foundations of the building are constructed with stones and bricks 50 cm and 37 cm from the cell of the ground floor and 25 cm from the bearing walls of the inside, while the rest of the walls are 11 cm in thickness. At the same time, metal beams that are supported by the bearing walls of the structure and brick columns, are supporting the walls of the first floor which makes the two floors to differ in layout. In addition, the colored tiles in the entry and the wooden doors and windows inside and out, give an interesting scene to the building.

The building used to be a hotel with stores on the ground floor. In the ground floor there are stores and quite central of the south-west view (from Naousis street) there is the door of the hotel. Thirteen rooms exist and are placed in the perimeter, while the flow to them is done through two elongated corridors that they are close to parallel with the rooms and they are lighted by the skylight duct of the middle zone. There ends the staircase with which the floors are communicating. There are four common sanitary rooms and a shower room. The room of the reception of the hotel exists in a small space between the staircase flatten in the entrance.

Due to the fact that the building has almost the same heights as the surrounding buildings, apart from some exceptions, for example in the south-west of the location, it has solar radiation for the most part of the day. Specifically, the roof has daylight as the sun shines and the south-west façade has sunlight in the afternoon. Throughout the day there is diffused light. For these reasons, it is suitable to place photovoltaic modules in an angular position in all surfaces of the roof, following always the existing slope, and in a vertical position in the south-west and south-east façade of the building.

Figure (64): Topographical map which indicates the building environment and the position of the building of interest (by the owner Eleni Pinopoulou)

7.6. Surveying the building

7.6.1. Introduction

In order to choose the case study, the first step was to research for the existing drawings. The condition of the building was evaluated as deteriorated, from personal experience, and thus it was not expected to find any clues. However, in the public authorities and the Town Planning Department of Florina, the city in which the building exists, there were a digital scanned file from the very first submission of supporting documents.

Unfortunately, these files did not coincide with the reality. As we can see from the figure , in the drawings the building had to be consisted by a ground floor and two upper floors (Figure 55). The ground floor has a distribution of four openings, three window frames and an entrance door, and at a first glance, the distribution is divided to: two thirds of the facade are the display windows and one third consists of the door and the other window display. As for the two upper floors, they are divided to three optically equal parts, with the very left and right parts to be divided into two window openings each, and the centered one with three. The parts are divided with obvious false columns which form the division on the two floors. In the roof, there is a curved crown centered to the facade magnifying the middle part of the facade. Plans from the other three facades were completely missing or never even created.

Figure (65): South-West and South-East Facades _Building "Diethnes"_Product of surveying

As for the layouts that were found, they are not clear enough to understand the interior and they did not correspond perfectly with the latter facade either which is an error itself as the layouts of the floors and the facade have to correspond in order to be built.

From the Town Planning Department, Mr. Michail Papagiannakis, who is the chairman of the local Department, claimed that there were drawings and details that accompanying the original files and they were those with which the existing building was built, but there were lost.

At the same time, the connection with one of the owners, Ms. Eleni Pinopoulou was made. She gave the files that contained some information of the building, a topographical map of 2010 and the governmental decision for the building being claimed as listed and protected. Thus, at that moment it was decided surveying the building inside and outside since it was not clear the structure and the size of the building and the correspondence between façades and layouts. So the surveying made to provide drawings of the building's layout and sections and to evaluate the fabric's possibility to accept photovoltaic application.

7.6.2. Methodology of surveying

The approach that was followed for surveying was an "extensive" one or, in other words, a low-resolution survey because the purpose was to form a general statement on the condition of the building for restoration and photovoltaic installation (David Watt, 2011).

The initial step in a case of a survey usually is to make a first impression and contact with the element of case study. But, because of an achieved familiarity with the environment, such an impression was not necessary. The process began by making a sketch with the rough proportions of the building's footprint and the surrounding roads, pavements and buildings. The measuring started with the north façade and then continued, counter clock-wise to the west- southern and the south-western façade. As it had to be done, the measurement was contacted in a fluency as a continuous polyline, which contained columns, window frames and glass. Further on, in order to keep tracking any deviation, extra measurements had been taken into account. These were consisted of new sets of dimensions, which were registered per two pseudo columns. Once all horizontal alignments were measured, all the heights conducted, like the building's staircase, the heights of the windows and the ornamentation of them, the heights of the balconies and the total height of the building, as well. The same flow was followed to the other facades.

The instruments, used for this process, were two classic measuring tapes with different lengths and scale, a laser- measuring instrument in case of longer distances and the human height. The latter was used in order to illustrate the interaction through the human experience in the urban environment. This part was very important for the application of the photovoltaic modules, since it will contribute the dialog which

2

3

Figure (66) : Layouts of 1) ground floor, 2) first floor, 3) attic _Scale: 1:300(Survey Document) (Personal Document)

would flourish between the technology and the user.

After finishing the external surveying, the process continued with the internal one. This was important only to acknowledge the state of the outer shell of the building and the main structure. There were rooms, staircase and an attic. From all the internal measurements, the two most significant parts of the process, were the balconies and the attic.

The having access to the balconies, the ornamental elements on the first floor were able to be measured in detail, since they appeared some differences with the ones on the ground floor. In addition, the surface between the windows and columns was detected and evaluated as a possible solution for the photovoltaic module application. Secondly, by visiting the attic, there were small “rooms” that gave us access to the inside view of the bare roof, as it was lacking insulation and the structure and tiles were clearly visible from the inside (Figure 67).

All the needed measurements and calculations were executed, with the intention to gather the necessary information to build up the model in a 3D design program, in Rhinoceros.

7.6.3. Barriers & Challenges

Provided that the building is in a bad condition, there were barriers and difficulties in the surveying process.

At first, the lack of preservation was visible to the outside, since the plaster was worn off in some places and the brickwork was noticeable (Figure 58). In addition, in the northern façade, the water from the precipitations had made marks on the plaster and huge demolition, which tried to be covered with cement. The draining system was causing more issues than there were to be solved. This had caused cracks to the first-floor plaster, which is dangerous to the inside rooms as well. This uneven surface had caused different dimensions in elements that had to be even when they were in primal situation. Furthermore, the wooden door and window frames were swollen by the time and the extreme weather conditions, and thus the sections differ from element to element, but also sometimes to the same element.

Another barrier was the measurement of the ground and first floor. For the ground floor, the café at the south corner of the property and the small rooms in the south-west and north façade were locked and unable to enter. For that reason the layout is clear at these points and only the entrance of the building has been surveyed. In the first floor, most of the balconies were in bad shape and thus the access was questionable and dangerous, and also because the surveying was made lacking scaffolding system, which in professional surveying cases that is inevitable (Figure 70).

Figure (67) : Internal roof structure (Survey Document) (Personal Document)

Figure (68): Destructed façade, worn off plaster detail_North-West Facade (Survey Document) (Personal Document)

Damage Registration

Regarding the deterioration of façade, the south-west elevation, the face with the main entrance and the most visible from all angles, appears to have the highest degradation percentage of all faces, around 50 percent of the plaster is missing (Figure 69). The north-west elevation appears fall-out mostly on the ground floor and some cracks on the first one. Lastly, the south-east elevation appears a very low percentage mostly on the ground floor. The collapse of the façade consists from the outer layer of the plaster with the painted outer layer, but in many case the deterioration reaches until the brickwork which is at least 2cm of plaster. The remaining parts, however, are not in a good condition also because they have been inflated and ready to collapse.

Likewise, all wooden frames and wooden shutters have been inflated too from the weather conditions and the age of the construction.

From the pattern which is created by the missing parts, it appears that the abruption of the plaster is due to the water drainage that comes from the roof. The same pattern appears is created also near the water drainage on the north façade. Excessive moisture is the most common and damaging source of deterioration and decay that affects historic buildings. The cause to the problem may be distinct but is usually concealed and undetected until decay is advances. In addition, based on D. Watt, changes in our lifestyles have also created higher levels of moisture. The will for energy efficiency and personal comfort, with the increased use of insulation products, double glazing and draughtproofing, the withdrawal from the use of open fires and the desire for higher levels of space heating, all have an effect on the internal environment (David Watt, 2011).

Furthermore, when water absorbed into a porous material freezes, it exerts a pressure on the internal structure of the material, causing fracturing and disintegration. This is usually seen in masonry, when the face of the brick or stone breaks and the section perpendicular to the penetrated surface. Water can expand at temperatures that are 4^{o} C down to - 20^{o} C. This expansion is the cause of water pipes bursting in the cold winter. Frost wedging occurs in climates that are cool most part of the year. Particular damage may be caused by cycles of freeze/thaw action. The susceptibility of a material to such damage is related to the size and distribution of its internal structure of capillaries and pores. For water to freeze it requires sufficient space for the ice crystals to nucleate. Thus, materials with a fine pore structure will suffer less damage than those with larger pores in which ice crystals can grow (David Watt, 2011).

The reasons behind cracked and detachments of plaster in a façade (Figure 71) could also be an outcome of using incorrect materials and techniques, such as excessively thick coats, inappropriate mix strengths or overworking. In addition, failure of bond between stucco and underlying fabric, caused where there is inadequate key, the substrate is dense and has limited absorption, or where there is contamination of the surfaces. Last but not least, a failure of paint finish could be connected with the thickness of paint applied to the plaster (David Watt, 2011).

The pervious facts have lead to the conclusion that the roof condition is very poor. Together with the photographs taken from inside the roof, which shows no fragment of insulation, describe a deterioration of the roof.

Figure (69) : Damage registration on the south-west and south-east facade (survey product)

Figure (70) : Destructed façade, worn off plaster _Soith-West Facade (Survey Document) (Personal Document)

Figure (71) : Plaster damage on south-west facade (survey product)

7.7. Conclusions

The reason behind the survey is the lack of correct drawings in which my case study application would be based on. Without those, it was impossible to explore the possibilities and the extend of the application. In addition, without the drawings it was impossible to construct the model and the urban environment in Rhinoceros, and to run the solar analysis simulation in Grasshopper, and if this was the case, the calculations would be far from reality. For all these reason, the survey was vital for the continuance of the photovoltaic application.

With the survey, many and different issues revealed regarding the state of the building, inside and outside, and the damage which exists due to the abandonment and weather conditions. Nevertheless, a huge opportunity was unveiled for solar installations, especially on the roof due to the orientation and the size, and also for restoration and preservation opportunities. Furthermore, the outcome of the survey, the drawings, form a starting point for any further restorative operation, which did not exist before. For restorating the property more extensive surveying and detailing should be performed in order to achieve a complete image and to form a correct restoration plan. The latter seems to be urgent because, just from the external condition, the building is deteriorating fast due to the weather conditions and maybe has to be evacuated soon if the roof is not properly restored.

Based on damage registration, the survey opens the prospect to restoration do to the fact that 50 percent of the plaster on the south-west façade, which is also the most important from all elevations, has worn off due to weather conditions and the poor roof condition. In addition, the shutters and all the wooden frames should be replaced since they have been expanded from age and weather conditions. That said, a conjectural building restoration could be realized by different means based on the budged. However, installations which include solar modules are providing both impermeability to weather conditions and can contribute to the building's energy demand. Thus, instead of replacing the window glazing, a combination with solar-glazing and regular double glazing, or restoring the roof surface with solar tiles, instead of standard ones could be a solution.

All in all, with the survey, many people who did not know much about the specific building, got motivated to explore more about the area. Furthermore, people who have already good relation with the building and its history, the survey gave them the opportunity to share their knowledge and, also, were interested to know what was to come from the case study analysis and this thesis project.

8. Application of PV technology on the case study in Greece

Figure (72) : Current Status of building "Diethnes" (https://www.dpgr.gr/forum)

8.1. Introduction

Every heritage case is different, and each case is identified by various features, such as the environment, the different past and, also, by different inhabitants. However, if cultural heritage is going to join the energy transition, it has to be through process without compromising the history that they represent. So the question is how and to what extent should or could heritage buildings be included in this process.

In this chapter, the building of interest is the one from the previous Chapter, Chapter 7, the building "Diethnes" in Florina, a city in north-wester Macedonia, in Greece (Figure 72). In this Chapter, the design and its process of the buildings solar interventions are illustrated, based on two different energy scenarios, a hotel and a multi-function, including the cultural center. The scenarios are chosen based on the past use of the building and the needs of the urban environment that this building is part of. Nevertheless, the process itself and the possible solutions presented could be embedded to a broader system of applying solar energy to heritage buildings.

8.2. Process & Design requirements

The process of applying photovoltaics on the façade of the building starts with a base situation, which is the current state of the building, that was mentioned above, the climatic zone, in which it exists, and the solar irradiation, which both are going to be explained. Nevertheless, the renovation of the building is not going to be included. The climatic data are important for the part that follows, which is the energy scenarios, in which the building's potentials for photovoltaic application are going to be evaluated.

The design requirements, in which the matrix is going to be based on, are formed basically from all the previous chapters. The key points that were formed from the literature, the evaluation of the case studies and the building's own requirements have set the guidelines.

8.2.1. Base situation

The current situation of the building is characterized by a deteriorated façade, showing cracks and dstroyed materials, wooden frames harmed by weather conditions and broken glass (Figure 72). However, the reconstruction is not going to be the focal point in this research and so it is assumed that a reconstruction process is running at the same time. The aim here, based on general research, is to make suggestions and propose design solutions that would be combined with the reconstruction of the old structure.

<u>Climate</u>

Greece is set between latitudes 34 º and 48 º in the Northern hemisphere, under typical Mediterranean climate with relatively warm and dry summers, mild and rainy winters and generally long sunshine periods throughout the year. In Greece the climatic condition changes mainly due to the topographic configuration and extended variation between land and sea. The cold and rainy season lasts from mid-October to end of March and the hot and dry season from April to October. The average minimum temperature ranges from 5 º C to 10 º C in coastal areas and from 0º C to 5º C in island areas. The winter is milder in the Aegean and Ionian Sea regions than in northern and eastern Greece. The warmest period is within July and early August when the mean maximum temperature ranges from 29 º C to 35 º C (Hellenic Statistical Authority, http://www.statistics.gr)

Greece has high solar energy resource. The average annual solar radiation is estimated to be 1570 kW h/m2. In major parts of the country, the sun shine hours are more than 2700 h/year, or 7.5 h/day, while in areas like southern Aegean, the hours of sunshine are 3100 h/year or 8.5 h/day. High solar resource can be used for heating and electricity production in the country.

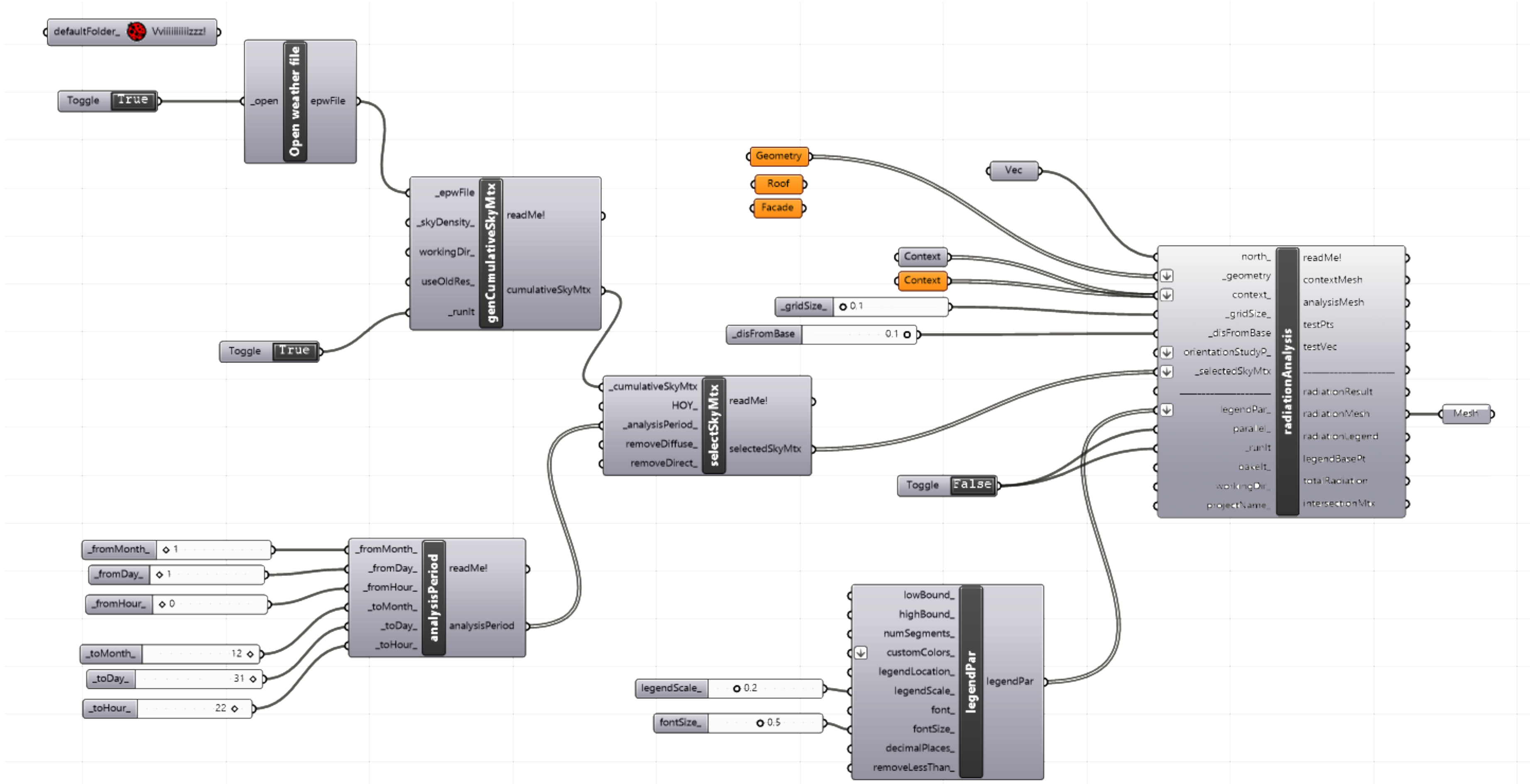


Figure (73) : Grasshopper code with the plug-in Ladybug for solar radiation analysis

Model creation and solar radiation analysis

After gathering the weather data and forming the drawings from surveying the building, which are presented in Chapter 7, the model has to be made in computer in order to simulate the solar radiation which receives annually. The model was constructed in the 3D program Rhinoceros based on the drawing and photographs taken by surveying the building. The next step was to form the code for the simulation. A simple code formed in Grasshopper, plug-in of Rhinoceros, which was fed by the weather data of the region, city of Florina, and the given geometry, in this case consisted by the building "Diethnes" and the surrounding urban environment. The code was made by components of a plug-in in Grasshopper, called Ladybug, which is constructed for bioclimatic analysis, and provides different environmental analysis (Figure 73). Thus, by running the code, the solar radiation map was created. The code was built in such a way that the duration of the analysis and the size of the grid analysis could be determined.

Solar radiation map

There are fundamental aspects that have to be sorted out first and these are related to the south-west façade and the roof, since these are going to be the focal points of the design. The south-east façade is structured with the same pattern as the south-west façade and the design solutions could be used with the same way. That is the reason why this is considered as a minor aspect. The first step to this case study research is to make a computer model and calculate the annual solar irradiation map in the south-west façade, and the roof (Figure 74). In addition, the northern façade is excluded from the process of the panel application since is mostly shaded and has little to no solar value, but without being excluded from the renovation process that it is considering to be conducting simultaneously with this research. The urban environment is always included in the calculations since the shading effect is the element which would define the solar application in a dense city (Figure 75). At first a simplified model was made in order to build the process in the background and visualize the first results. As a next step, a more complex model was formed in order to have a better view of the reality. As it can be seen from the figure, the building's façade is consisted of many decorative elements and not every available face is suitable for photovoltaic application, due to curvature and size (Figure 76). In addition, the particular finding with the map roof is that some parts are having little solar irradiation, even if they face in the most optimal position (Figure 77). However, in a bird-eye view picture of the area shows existence of solar irradiation (Figure 77).

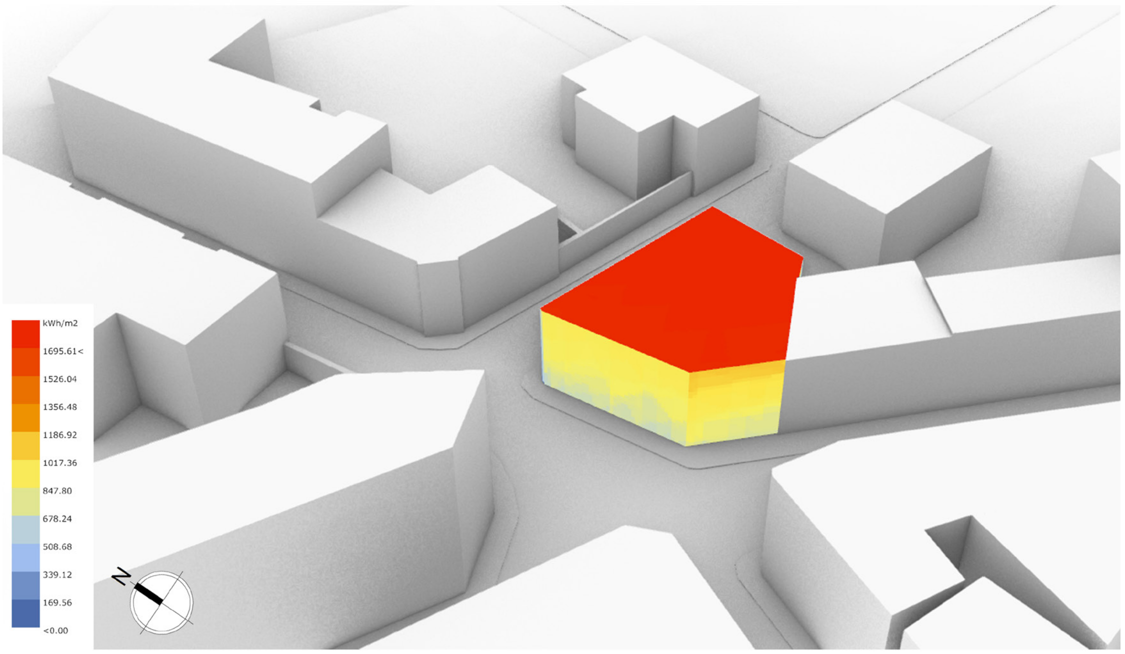


Figure (74) : Annual solar irradiation of the building.

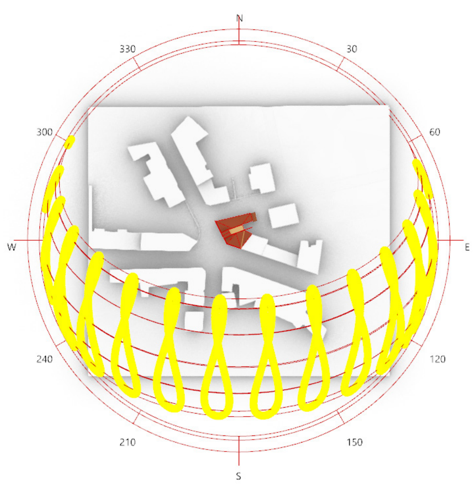


Figure (75) : Annual solar irradiation diagram

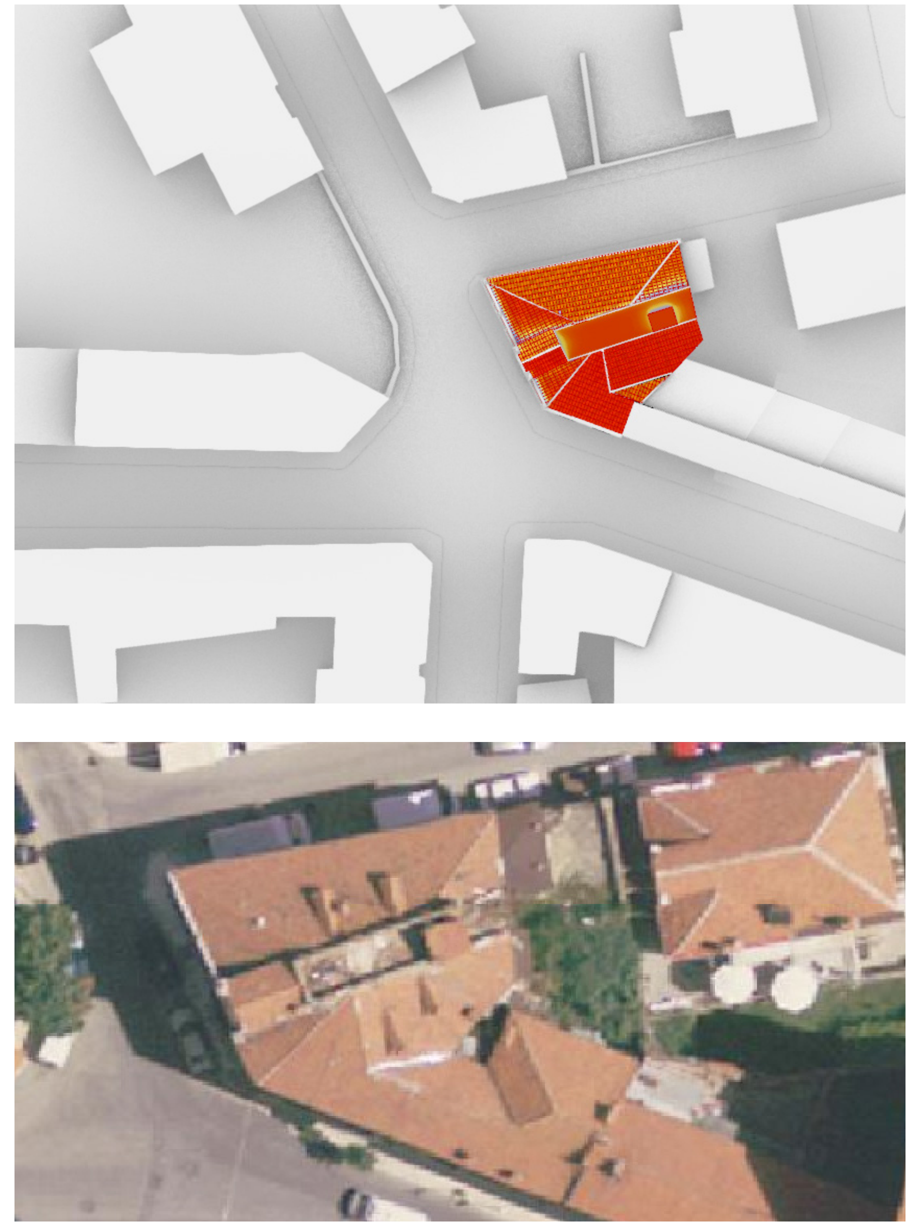


Figure (77) : Bird-eye view of the building area (left),annual solar irradiation map of the roof (right)

Figure (76) : South-west (right) and south-east (left)façade's annual solar irradiation map.

8.2.2. Energy Scenarios

Two different energy scenarios are chosen for this exploration with different energy demands. The latter is chosen to illustrate two cases with alternative module adaptation.

The first energy scenario has the function of a hotel, which was the original purpose of construction and constitutes the high energy demand option. This selection was made not only to wake up the old spirit of the building, but also to be more appealing to possible investors.

The second energy scenario is a multi-function, which means that could host different programs, and it is the option with the lower energy demand, since it would be in use for a small period of time daily. For this purpose commercial use was selected for the ground floor, for the reason that the ground floor of many of the surrounding buildings has the same occupancy, and cultural use in the upper floor, due to the fact that the first floor has a similar use at the current period of time.

The building is consisted of ground floor (257 m2), first floor (233,8 m2) and the attic (38 m2). The size of the living space is important for the energy demand calculation based on the chosen function in different energy scenarios.

Hotel

The hotel function was the reason why the building was constructed in the first place. It was an important addition to the city of Florina in 1924. Yet, the way which the owners distributed the different rooms or how they operated the traditional café that still exists in the south corner on the ground floor, it is unclear. Considering the economical state that the country is at this point, as a hotel, the building could be alive all year long and also attract possible investors in order to fund this rehabilitation project.

Because the city center of Florina is a heritage one, which is composed from heritage culture from two different styles, one style with ottoman influences and, also, the neoclassical movement, it could be transformed to a leaving museum without the actual function of a museum yet. Providing them with different functions, such as hotel, café, residential or commercial, they become a part of the functioning urban environment and correspond to the reason why they have been built in the first place. In addition, in order to make them a leaving space with the standards of our time, they should be restored and refurbished, and thus to maintain their existence for the future generations.

An example of the importance of this energy scenario, which has been found through literature research, is the case of "Spread Hotel" (Albergo Diffuso) (Figure 78) of a heritage building in southern Italy (Tagliabue, Leonforte, & Compostella, 2012). This project is a match with the case study, as they are both in Mediterranean and the weather conditions are quite in the same range.

The "Spread Hotel" renovation concept intends to preserve the heritage character of the site, boost social environment and secure economic feasibility. The project's goal is to apply renewable energy sources on a historic building in the concept of nearly

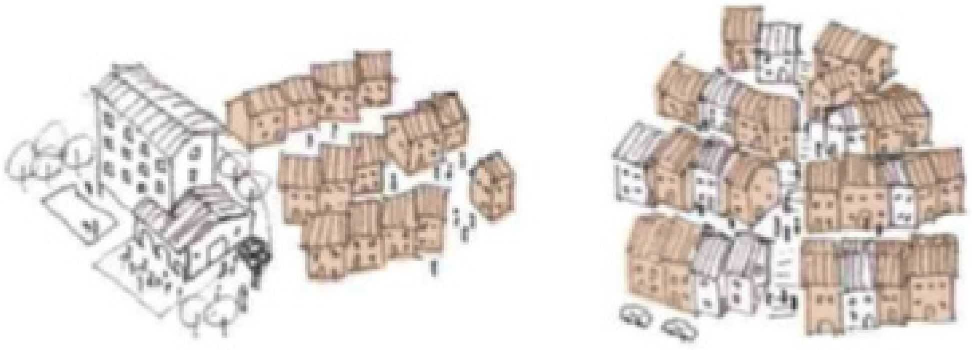


Figure (78) : Ordinary Hotel (left) and Albergo Diffuso (right).

zero energy buildings. Generally, the case faced several obstacles, because of the age of the building and decay issues. The followed method is based, mainly, on analyzing the environmental conditions and the built environment features.

The solar radiation on the building's surfaces was evaluated by taking into consideration the high standard quality for inner spaces, for the hotel program. Important for the case was the exploration of solar gains for winter period and the possibility to produce energy, by integrated photovoltaic systems, on building surfaces, which would respect the regulation constrains of the historic center. Monocrystalline silicon modules were used to cover an area of 40 m2 on the south side of the tilted roof. The correspondence of the angle of the module with the tilted roof, allowed getting the maximum use of the sun's energy across the seasons and the energy produced by the photovoltaic system can entirely cover the winter and summer energy use (Tagliabue et al., 2012).

The idea of "Spread Hotel" benefits the local community and also the image of the country by reconstructing existing heritage buildings. This itself promotes environmental responsibility by upcycling the structures, and in combination with the use of renewable energy sources and climate strategies, spreads the word for a smoother energy transition.

However, the difference between the building "Diethnes" and the "Spread Hotel" is that it is promoted a grid of traditional motels placed upon heritage buildings, while in the case study in Florina, a single building was researched. The concept of "Spread Hotel" could be part of further research for heritage cities or city centers, and that is why it is a valid clue supporting the proposed energy scenario.

The energy data for this energy scenario are based on the European data of 2016 for Greece. Thus, the energy demand for this function is 752.37 kWh / m2 annually, without any energy reducing intervention. Nevertheless, if renovation is in progress at the same time and based on the National Legislation for Construction, the new energy demand of this function is going to be 366.63 kWh / m2 annually, and the energy saving would be 51.27 percent. The total energy demand for 528 m2 in this climatic zone and with this function would be 193,873.95 kWh, 193 GWh annually.

Figure (79) : Concept of solar module application

Multi-function

The second energy scenario that is going to be explored is a multi-function situation. In this case, the ground floor is going to maintain the commercial use, as it has now but with all the northern shops to be functionable. The upper floor is going to keep the cultural use, from the one site as ethnological museum and on the other site as a multi-purpose rooms which they will continue to host different art clubs in the city.

The energy data for this energy scenario are going to vary due to multifunctionality of the space. Thus, the ground floor, as a commercial use, based on the European data of 2016 for Greece, is using 493.15 kWh / m2 annually, without any energy reducing interventions. The upper floor, as an educational use in general, is using 243.65 kWh / m2 annually. The attic is not in use and is not going to be used as a functioning space. Nevertheless, if renovation is in progress at the same time and based on the National Legislation for Construction, the new energy demand of this function is going to be for the commercial use 249.77 kWh / m2 annually, with energy saving at 49.35 percent from the state without the energy efficiency measures, and in the educational use would be 199.90 kWh / m2 annually, with energy saving at 50.79 percent. In total the energy demand for 490.8 m2 for this climatic zone would be 96,779.71 kWh, 96 GWh annually.

8.2.3. Design Requirements

Based on literature research, research on reference case studies and the building's own requirements, the design requirements formed for solar intervention in the building "Diethnes".

These design guidelines are:

Roof application

- Since the roof is not visible from street view, color can differ from the existing.
- The photovoltaic panels should fit the different parts of the roof, and since its uneven shape, the smaller the size of the modules the more preferable.
- The application should be in groups in order to be organized.
- The panels should correspond to the surface structure of the roof by being parallel to the application surface.
- Avoid reflectance on the outer surface of the module, which could lead to glare.

Facade application

The parts which are going to be applied in the **plaster** should….

- correspond with the shape and color as the surface that they were going to be applied on.
- correspond to the fragmented surface of the façade, i.e. the vertical parts between the pseudo columns and the window frame.
- be mounted in a lightweight frame.
- correspond to the surface structure of the plaster by being parallel to the application surface.
- avoid reflectance on the outer surface of the module, which could lead to glare.

The parts which are going to be applied in the **glazing parts of windows** should…

- correspond with the shape of the window glazing.
- be grouped as much as possible or be evenly distributed by creating a pattern.
- be light weighted.

The parts which are going to be applied on the **shutters** should…

- be light weighted.
- correspond with the shape and color as the shutters which are going to be selected during the restoration plan.
- correspond to the surface structure of the applied area.
- avoid reflectance on the outer surface of the module, which could lead to glare.

The **additional parts** which are going to be applied on façade should…

- correspond with the architectural character of the building.
- be true to the purpose and not use excessive surface without a reason.
- be flexible to uninstalled if not wanted.

8.3. Boundary Conditions and Assumptions

There are some boundary conditions that have to be set before beginning with the design. There are no specific guidelines and regulations for applying photovoltaic technology in a heritage building in the Greek Decree. The only regulation found in a footnote that nothing is allowed to be changed in a neoclassic building without the consent of local cultural authorities. Thus, the guidelines that are going to be followed are for the Flemish and Dutch Decrees, which there were mentioned in Chapter 3. In addition, the would be the assumption that changes, such as installing insulation and new window frames and restoring the missing plaster pieces from the façade, would happen in the renovation process and are going to be considered as existed. Finally, since the image of the building is the most important part of the process and for the final result, the solutions are not going to consider invading the structure of the building, such as drilling howls in the façade for the photovoltaic guides to be installed.

8.4. Concept idea for applying the modules

The concept idea for applying the photovoltaic modules on the heritage building will follow the process of a matrix. This is a set of conditions that provides a system in which the design grows and develops (https://dictionary.cambridge.org). For this reason, it is going to be a system of different solutions upon the different possible module application places, that will form a state which will evaluated feasible or not, based on the two energy scenarios.

The places that a photovoltaic module can be applied, as it is clear from the literature study, are: the roof and the façade. The latter, though, can be exploded to more detailed applications which are the bare surfaces of the façade and, the glass and the frames on the windows and doors. Additional elements can also be applied such as shutters, canopies and signs. These are going to be the one parameter of the matrix.

A first impression of the solar module application can be seen from the figure (Figure 66). In this figure, the possible places, in which solar panels could be applied, are illustrated in different colors. The color shades, which are selected as an early stage concept, are illustrating the impression that should give, like they are camouflaged. The reason why the camouflage approach is selected is because the architectural style is considered so important that no intervention is allowed, except the reconstruction into its original image. This method gives more opportunities to the application of photovoltaic modules without compromising the originality of the building.

Another issue that has to be considered to the design process, is the compatibility of the whole attempt. This characteristic, whenever is applicable, gives the leverage to reverse the process in the future without compromising the original structure. Thus, the invasion that would be proposed should have minimum impact on the structure.

8.5. Matrix

8.5.1. Matrix Base

The base in designing the matrix is to set the possible places of photovoltaic application and, as a next step, to set the different solutions for these areas.

To begin with, the possible options are presented in sketches that follow and which illustrate the change in the building' envelope with the solar module application. Since the architectural style of the building in this case study is repetitive, a unit which repeats is going to be the base of the drawings. Each unit consists of a door with double opening and a simple column in the ground floor, and a window, balcony, shutters, plaster and column on the first floor. In addition, a piece from the "crown" and roof complete this repetitive unit (Figure 80). The building consists of three repetitive units in the south-west façade and of two in the south-east façade. In the unit, the solar radiation analysis is performed in order to propose the different photovoltaic applications (Figure 67).

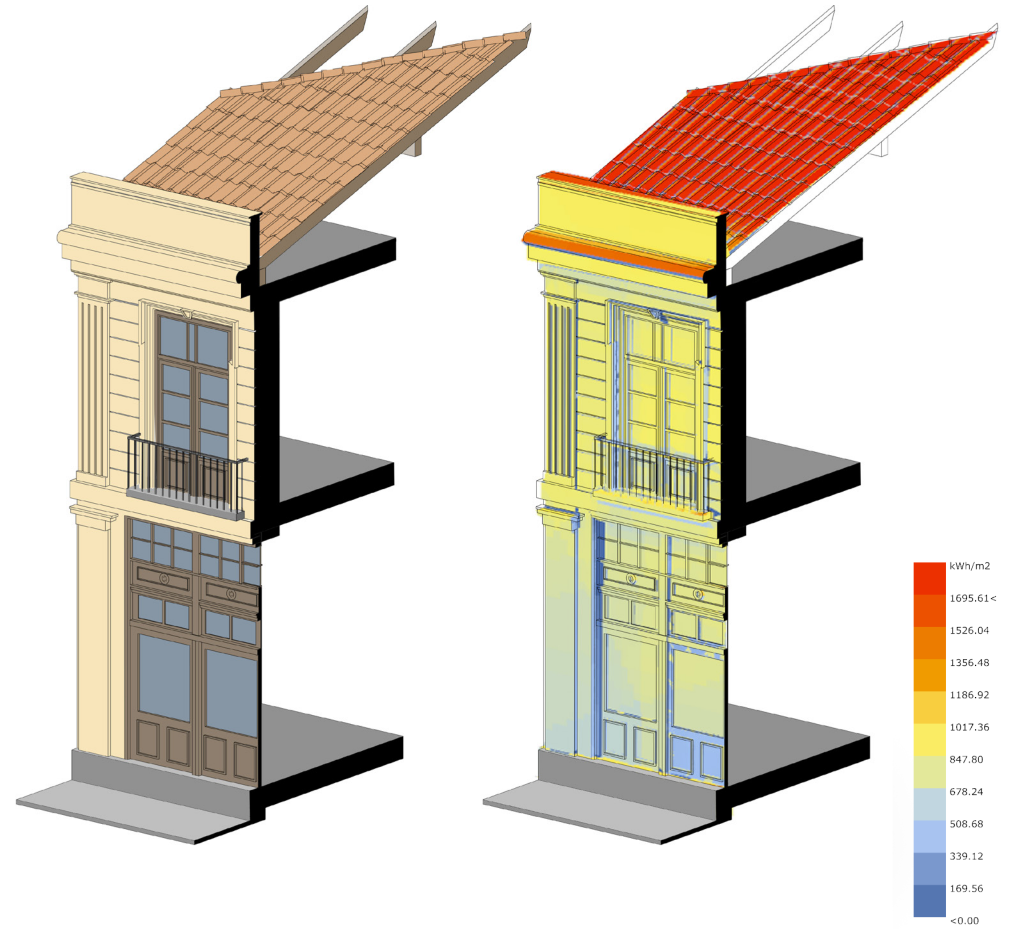


Figure (80) : Base unit (left) and its solar radiation analysis (right)

8.5.2. Panel Application

8.5.2.1. Sector : Plaster

Based on the solar radiation representation in Figure 80, there is an average solar radiation in the first floor of the building, and thus it is suitable for photovoltaic application. In addition, the south-west orientation is an asset for modules that are vertically positioned, like those in façade, because the sunlight that comes from the west can be perpendicular to the vertical surfaces. Firstly, the different colors of the modules are represented, matching the current one which is the yellow, and the original one which is the blue, color of the building's plaster. The technique can be the dyed sensitized or printed pattern on the module's outer glass surface, as it explained on Chapter 5, but the end result would be different. In the case with the ceramic ink pattern, depending on the dencityof the printed pattern, the cells could be seen or not. In the case of color coated, which is a multilayered coating deposited on the inner glass surface by low pressure plasma processes, the color could change by the change of sunlight or view of the building. In addition, the mountaining system of the panels is proposed. The first solution is based on the slate-effect of the plaster left and right from each window, and so each panel has a unique shape and size and with different number of cells. The second solution is to neglect the laceration, pretending that it is one piece and producing a large panel, unique in shape and size, in which the lines of the pieces would be printed. Of course, this could be feasible only with the printing technique (Figure 81).

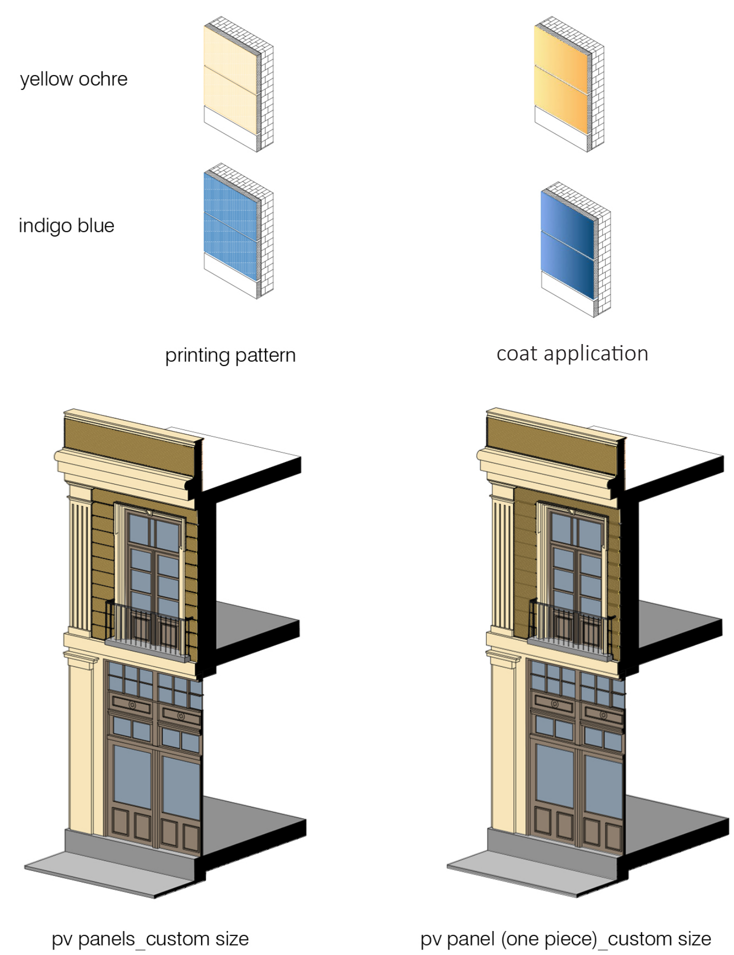


Figure (81) : Matrix plaster-application options and the possible colors.

Another proposed addition is in the building's crown which appeared to have a medium intensity of solar radiation (Figure 80). For that reason, there are two proposals which is based on the color and the technique. The color of the panel could be white, in a blue building's version, or yellow ochre, in a yellow ochre building's version. These color proposals are based on the literature research on Chapter 7. The technique, again, can be the colored or printed pattern on the module's outer glass surface (Figure 81).

8.5.2.2. Sector : Roof

The first representation of proposals is about the roof. Based on the radiation analysis, the roof is the highest group of surfaces on the buildings and thus has the highest solar radiation form any other surface of the building. Because the roof consists of sloped and flat surfaces. The capacity of each piece is different from the neighbor one in the same structure. Here are presented four different styles for the most dominant shape and size categories: 1)the wave style from Hanergy, which is imitates the waveshape of a classic terracotta tile application, 2) a grey panel with ceramic ink print,3) a terracotta-like tile attached with two photovoltaic cells, and 4) the SUNSTYLE in a rhombus shape and terracotta-like color (Figure 82). The selection was made between the different kinds of shapes of photovoltaic modules that exist on the market. The color in the printed grey panel and SUNSTYLE tile can be different, but the decision for the color selection was based on the fact that it would be interesting to research two terracotta-like solutions, more traditional ones in color, and two greyblue colored modules, more progressive solutions (Figure 83)

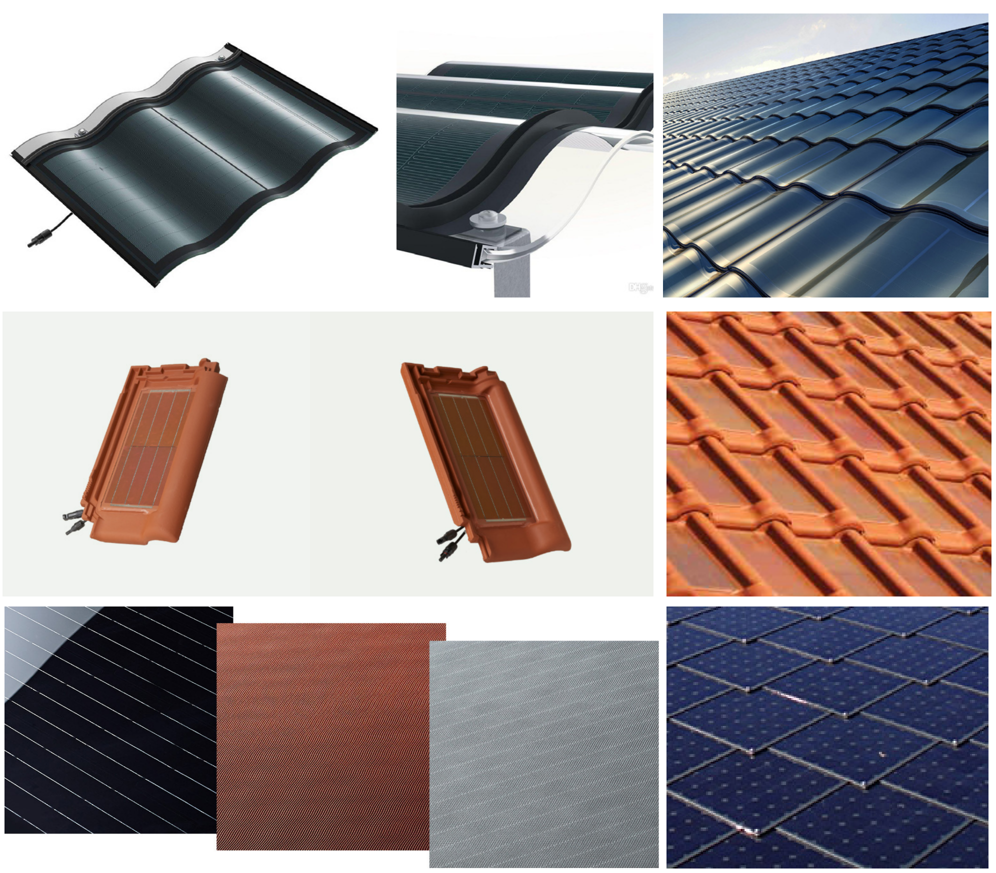


Figure (83) : Matrix roof options in dominant colors 1)the wave style from Hanergy, 2) a classic panel, and 3) the SUNSTYLE in a rhombus shape

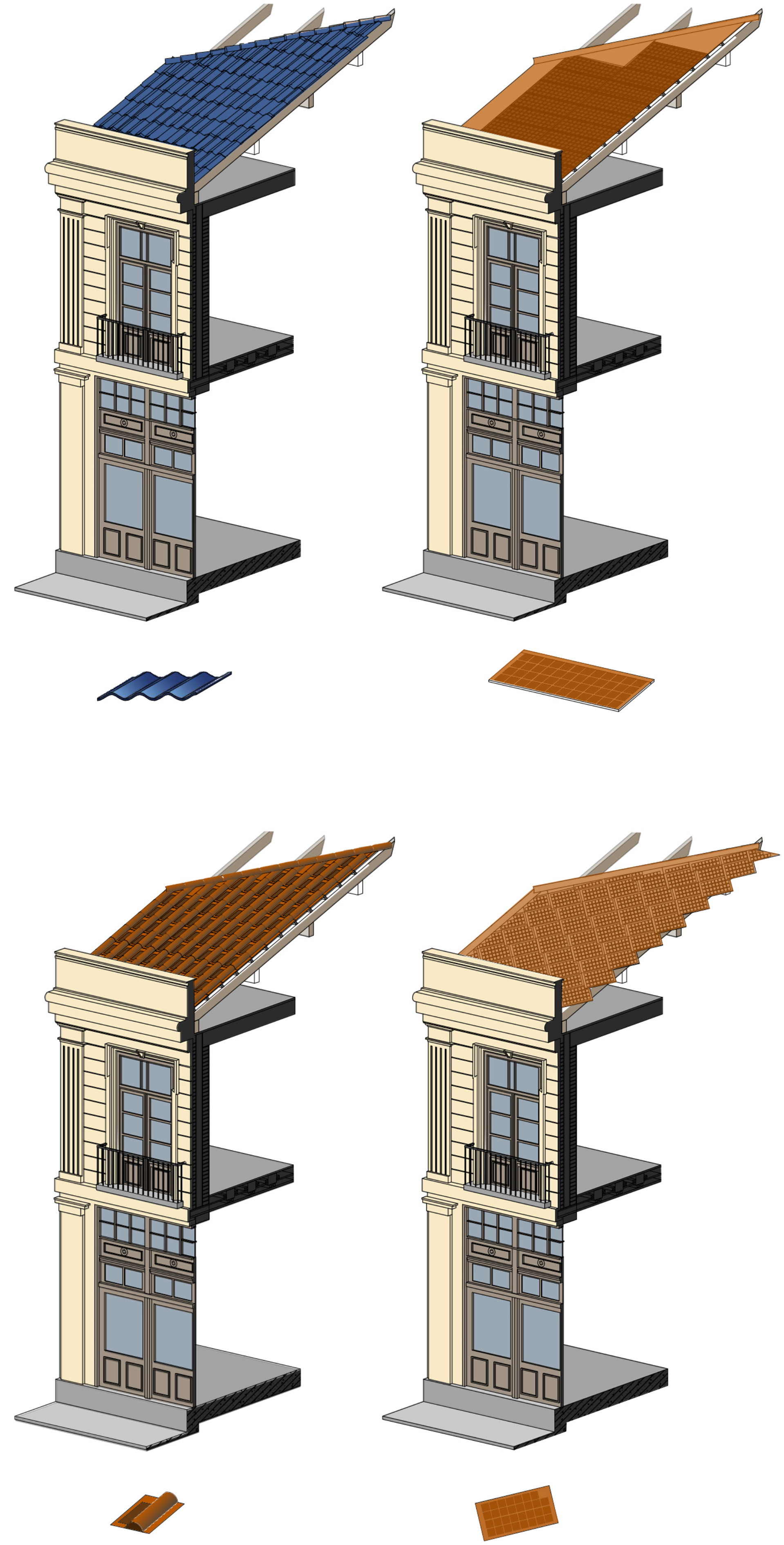


Figure (82) : Matrix roof options in dominant colors.

8.5.2.3. Sector : Window glazing

During the potential restoration of the building, the decision about where to place the insulation and if the frames should be replaced or not, should be made. There are two solutions for window application while restoring heritage buildings. The first one is a double layered window solution, where the old window frame and the replaced simple glass was maintained, while in the inner surface of the wall, a panel is placed, which contains the insulation, window frame and glazing. For this research though the second solution is used, which is the replacement of old window frames with new aluminum or wooden ones, to imitate the original ones, since there is no found value to the window frames but in the style of them (Figure 84).

Furthermore, based on the solar radiation analysis, the window glazing surfaces are receiving an average amount of sun radiation, with those on the first floor to have the highest, in comparison with the rest of window glazing. Thus, for the window glazing surfaces, the proposals are about the glass part, since the frame surfaces considered very small for an application in this case. So, in the first case, a laminated photovoltaic glass is proposed for the windows with the most radiation and above human eye level, in order to avoid the visibility in the inner spaces. As a second solution is proposing a semi-transparent photovoltaic glass from amorphous silicon that can be produced in any color, effecting though the efficiency, or in different transparencies (Figure 84).

In addition, amorphous silicon could be produced in different colors and could be used in a way that creates a stained glazing for the window. The building has already stained glass in the entrance door and the window above the entrance of the first floor. Thus an addition of that kind would not be unfitted to the building, but a part of it. (Figure 85)

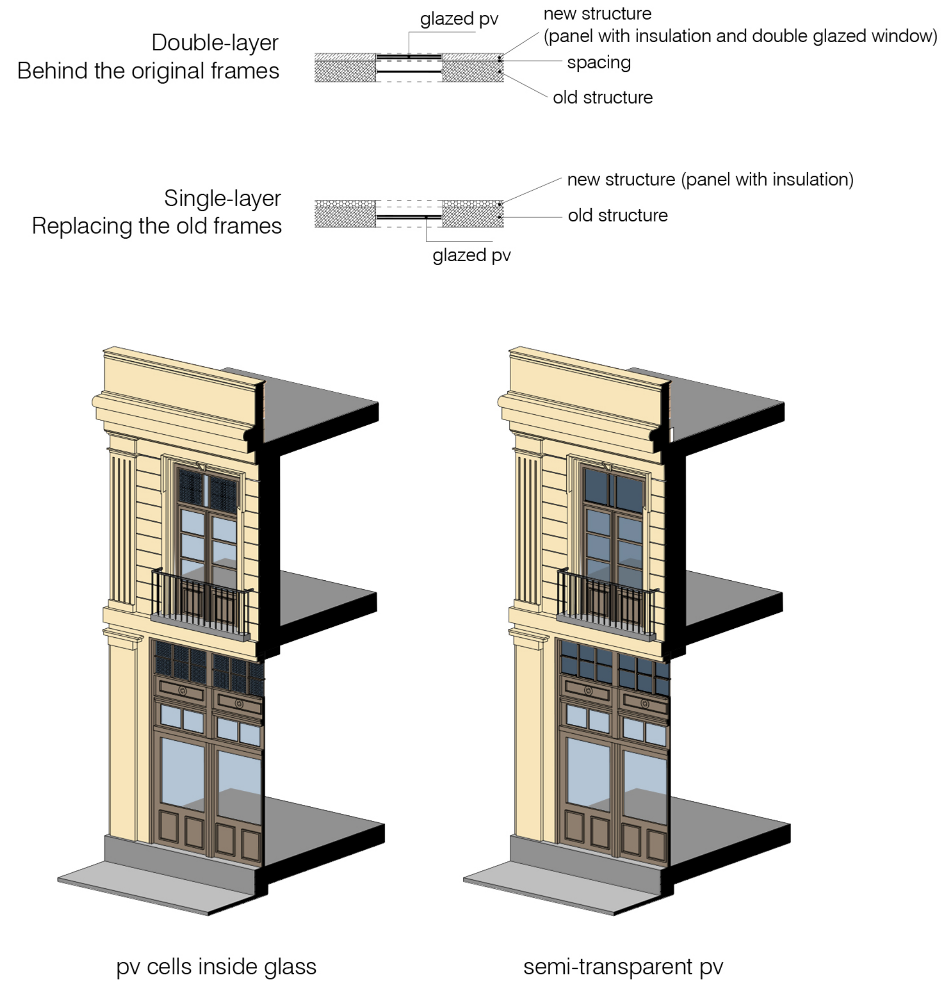


Figure (84) : Matrix window glazing options.

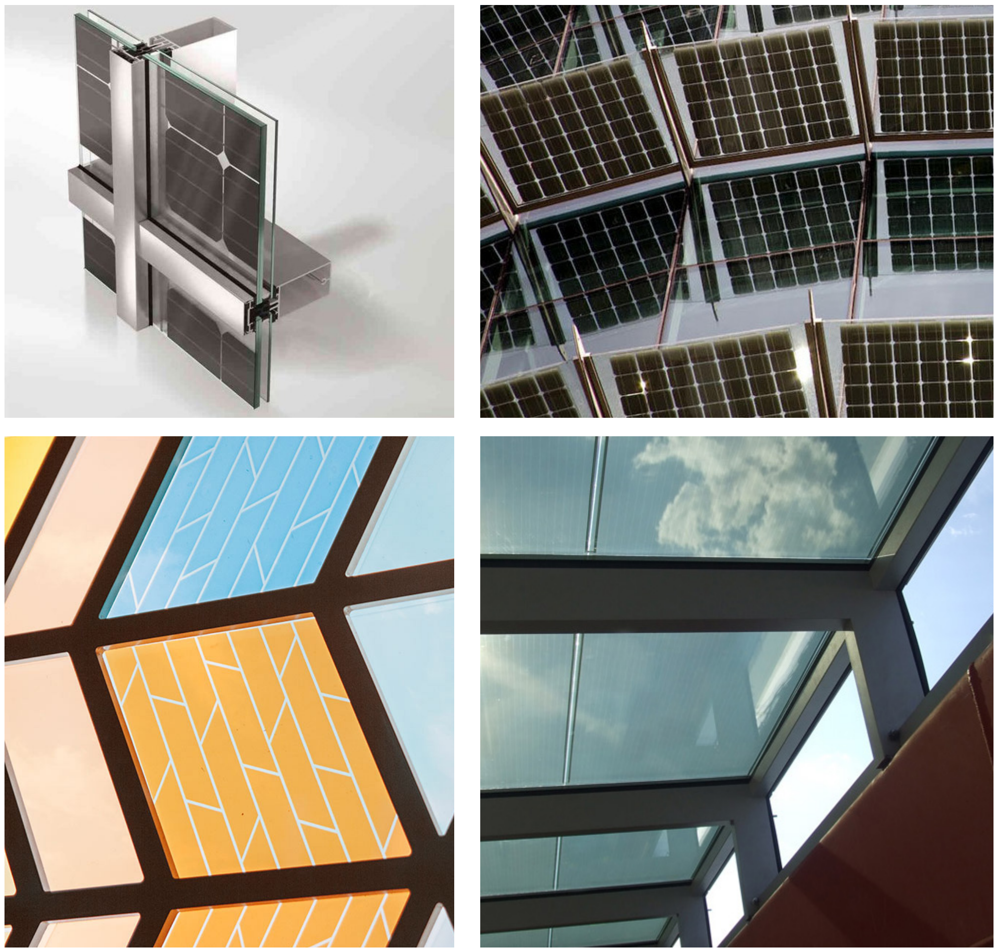


Figure (85) : Glazing options 1) laminated pv glass 2)semi-transparent pv.

8.5.2.4 Additional Elements

The additional elements are the shutters and balcony's rail that already exists, and a canopy, which could be additional.

The shutters on the first floor are of French style and the proposal is upon the louvres. The solution is a thin film application, because can be produced in small strips, either in the outer side of the shutters or in both outer and inner. The last solution could be replaced with bifacial thin film photovoltaics, but further research has to be performed to be available on the market (Figure 86).

The balcony's rail proposal is very limited since its application would affect the applications in the shutters and plaster. Nevertheless, it is proposed the replacement of the bars with photovoltaic panel, which could be from semi-transparent, printed or laminated cells (Figure 87).

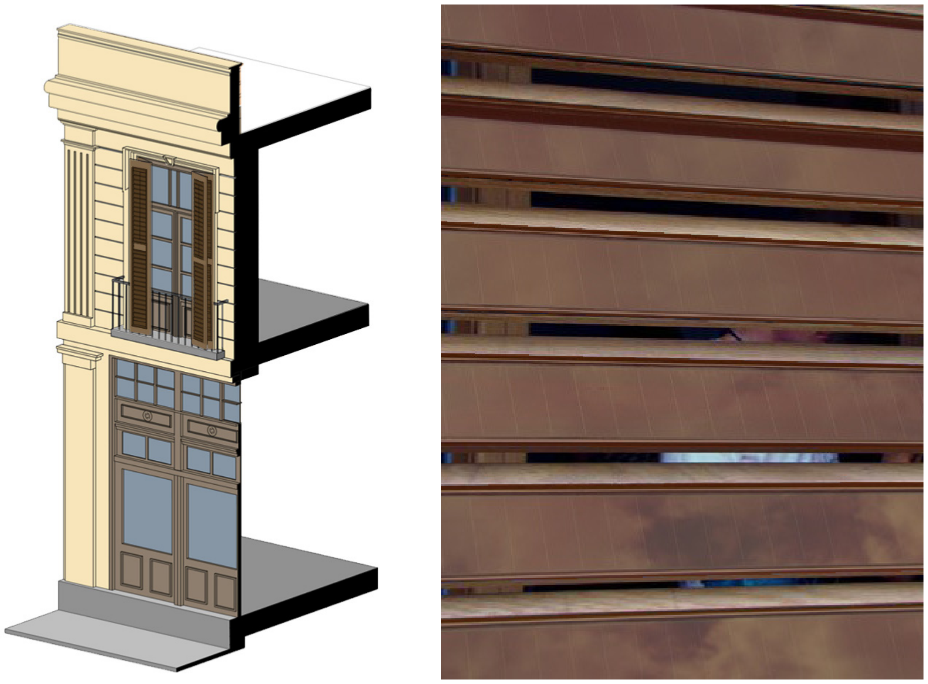


Figure (86) : Matrix options for shutters with normal thin-film pv or bifacial one.

8.5.3. Matrix Workflow

The above options have been organized in a matrix table in order to visualize all the possible solutions and evaluate them based on the criteria that have been derived from literature research, case study evaluation and specific building's requirements.

The first table is evaluating the proposals based on the design requirements, which have been mentioned above. The proposals are evaluated if they respect the architectural lines of the building, the shape, if they are visible from street views and heights, if they differ in color from the original version, if they are being installed in renovated structure or newly added, and the efficiency of the modules in the dominant colors or techniques (Figure 88).

Furthermore, four different proposed designs are formed which all reply to the proposed energy scenarios mention in Chapter 8, the function of a hotel and a multifunctional use of the building. It is worth mentioned that each design is one of many combinations which are produced from the matrix. These solutions are being presented and analyzed because they are the most dominant ones based on the design requirements.

<ins>#1 Design :</ins>The first design is consisted of: 1) slate module, monocrystalline cells, size 487 x 296 mm, color terracotta-like, low reflectance, on the sloped surfaces of the roof, 2) slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity, on the flat surface of the roof, 3) amorphous silicon cells, 30% transparency, size 850 x 520mm (0.44 m2), on the window glazing, 4) coated module (Kromatix), size 240 x 550 mm (0.12 m2) color yellow, low reflectance, on the plaster, 5) thin film cells, color golden brown, low reflectivity, on the shutters.

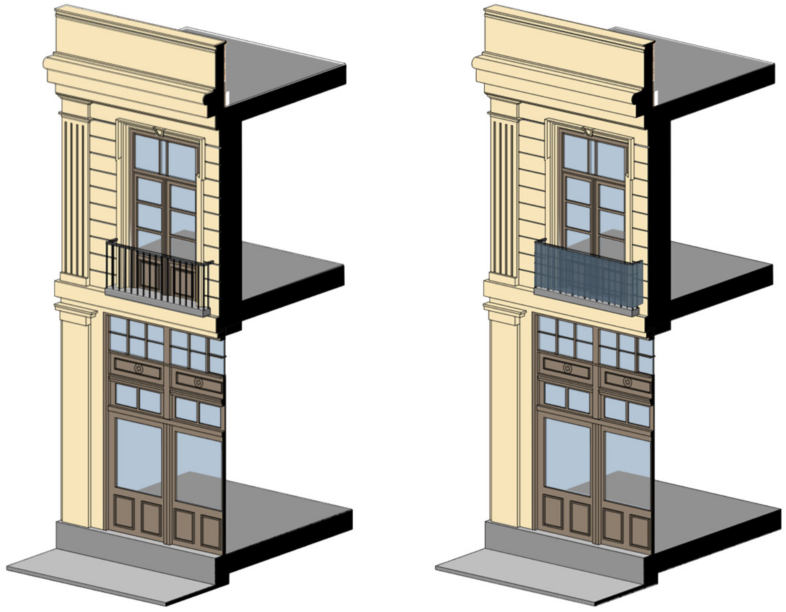


Figure (87) : Matrix options for balcony railing

<ins>#2 Design :</ins> The second design is consisted of: 1) terracotta tile with colored cell , size 487 x 296 mm, low reflectance, on the sloped surfaces of the roof, 2) slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity, on the flat surface of the roof, 3) Amorphous silicon cells, 10% transparency, size 850 x 520mm (0.44 m2) , on the window glazing, 4) ceramic Ink Pattern module (Colorblast), size 240 x 550 mm (0.12 m2) color yellow ochre, low reflectance, on the plaster, 5) Thin film bi-facial cells, color golden brown, low reflectivity, on the shutters.

<ins>#3 Design :</ins> The third design is consisted of: 1) slate module, monocrystalline cells, size 487 x 296 mm, color grey, low reflectance, on the sloped surfaces of the roof, 2) slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity, on the flat surface of the roof, 3) PV glass encapsulant, crystalline silicon cells, high solar density (15 % transparency), size 850 x 520mm (0.44 m2), on the window

roof

shape			color	"respecting" the lines	"following" the shape	visibility from... street views	visibility from... height	color difference	installing in ... renovated structure	installing in ... added structure	efficiency(Wp/m^2)
slate		color	grey				●	●	●		112-160
			blue				●	●	●		112-160
			terracotta-like				●		●		106-120
tile with cell		color	grey	●	●			●	●		90
			blue	●	●			●	●		90
			terracotta-like	●	●				●		80
diamond tile monocristalline silicon cells		color	grey				●	●	●		162
			blue				●	●	●		142
			terracotta-like				●		●		140
hantile roof tile monocristalline silicon cells		color	grey	●	●			●	●		—
			blue	●	●			●	●		105
			terracotta-like	●	●				●		—

plaster

production technique		color	"respecting" the lines	"following" the shape	visibility from... street views	visibility from... height	color difference	installing in ... renovated structure	installing in ... added structure	efficiency(Wp/m^2)
pattern	color	indigo blue	●	●	●		●		●	150
		yellow ochre	●	●	●		●		●	80
		terracotta-like	●	●	●		●		●	146
dye encapsulant	color	indigo blue	●	●	●				●	147
		yellow ochre	●	●	●				●	144
		terracotta-like	●	●	●				●	145
		white(if needed)	●	●	●				●	90

glass

type		color	"respecting" the lines	"following" the shape	visibility from... street views	visibility from... height	color difference	installing in ... renovated structure	installing in ... added structure	efficiency(Wp/m^2)
pv-glass amorphus silicon cells	color	blue	●	●	●		●		●	28
		yellow	●	●	●		●		●	28
		red	●	●	●		●		●	28
		green	●	●	●		●		●	28
		0% transparency	●	●	●		●		●	57.6
		10% transparency	●	●					●	40
		20% transparency	●	●					●	34
		30% transparency	●	●					●	28
glass encapsulant crystalline silicon cells	color	low solar cell density (38% tr.)			●		●		●	35.8
		high solar cell density (15% tr.)			●		●		●	48.9

shutters

type		color	"respecting" the lines	"following" the shape	visibility from... street views	visibility from... height	color difference	installing in ... renovated structure	installing in ... added structure	efficiency(Wp/m^2)
thin-film pv	color	grey	●	●	●		●		●	120
		golden brown	●	●	●				●	120
bifacial thin-film pv	color	grey	●	●	●		●		●	156
		brown	●	●	●				●	156

balcony

type		color	"respecting" the lines	"following" the shape	visibility from... street views	visibility from... height	color difference	installing in ... renovated structure	installing in ... added structure	efficiency(Wp/m^2)
panel	color	transparent		●					●	28-40
		pattern printed	●	●	●		●		●	28-40
		cell encapsulant			●		●		●	48.9-35.8
no change			●	●	●			●		

Figure (88) : Matrix table

glazing, 4) coated module (Kromatix), size 240 x 550 mm (0.12 m2) color blue, low reflectance, on the plaster, 5) Thin film cells, color golden brown, low reflectivity

#4 Design : The fourth design is consisted of : 1)a wave solar tile (Hantile), thin film, size: 721 x 500 mm blue color, low reflectivity, on the sloped surfaces of the roof, 2) slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity, on the flat surface of the roof, 3) amorphous silicon cells, 20% transparency, size 850 x 520mm (0.44 m2), on the window glazing, 4) Ceramic Ink Pattern module (Colorblast), size 240 x 550 mm (0.12 m2) color blue, low reflectance, on the plaster, 5) Thin film bi-facial cells, color grey, low reflectivity

For these designs, the energy of each application was calculated and the table (Figure 89) presents the percentage of energy production based on the energy demand of each energy scenario. The two factors, the design and the energy scenarios, are independent from each other, and with the table a decision can be formed based on the wanted energy balance or the desirable design.

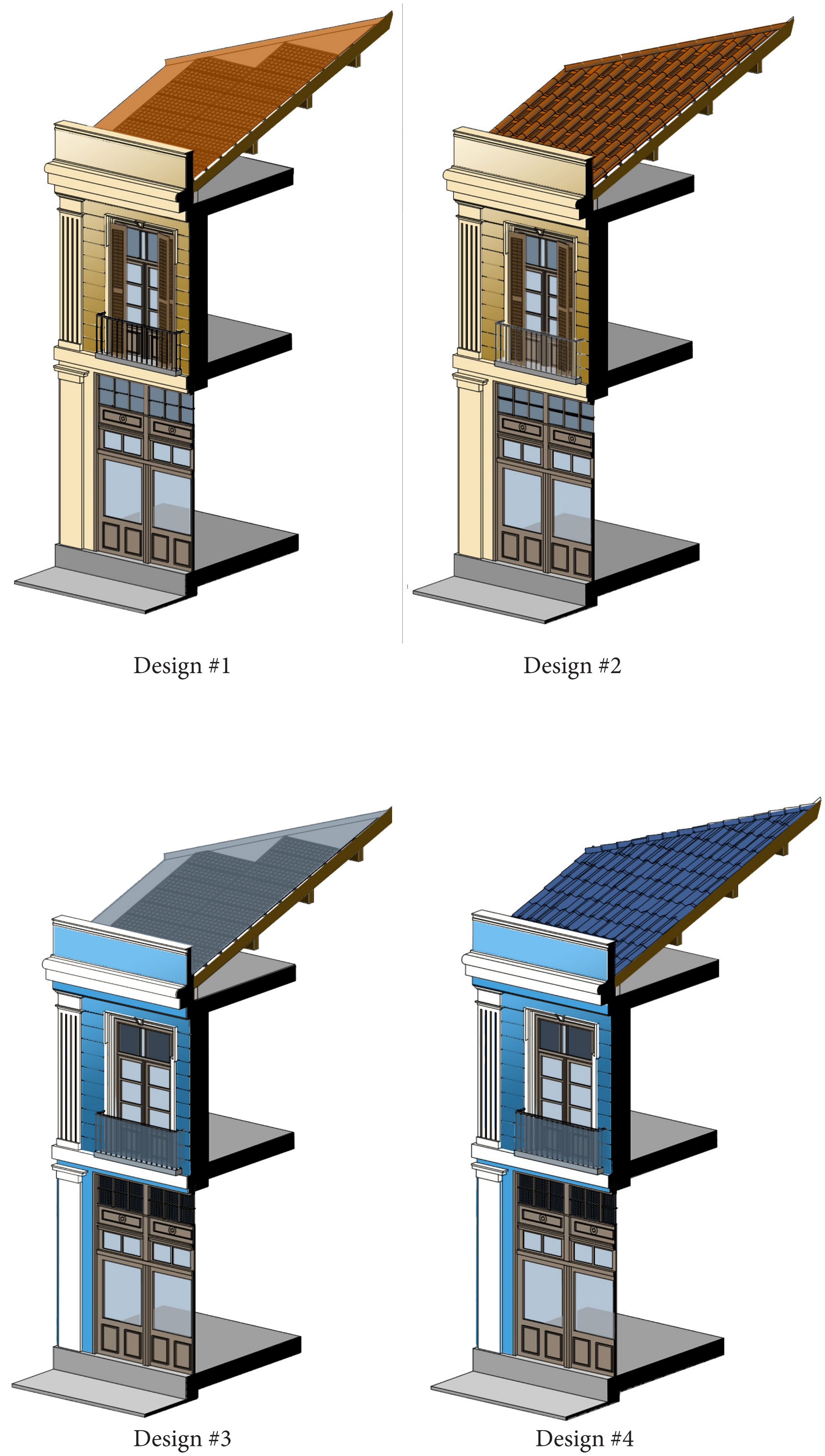
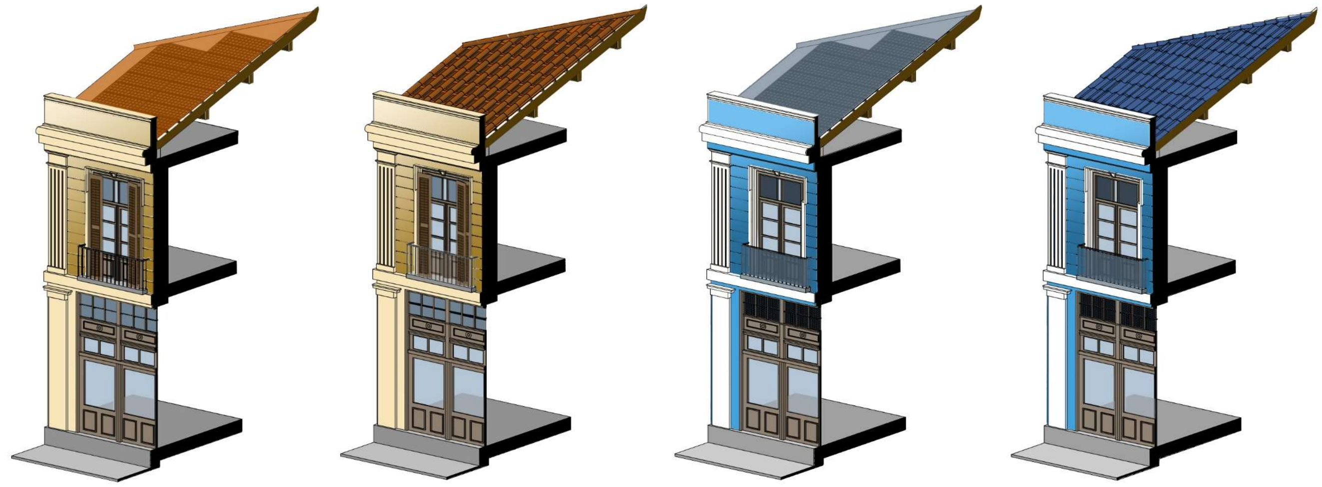


Figure (89) : Matrix Desings



Energy Scenarios/ Design	Surface Area		Design # 1	Design # 2	Design # 3	Design # 4
	Total energy rpoduction per design		26.35 GWh annually	25.55 GWh annually	35.02 GWh annually	25.02 GWh annually
Energy Scenario **1: Hotel** Energy demand 366.63 kWh/m2 annually	528.8 m2 (the whole building)	193 GWh annually	13.65 %	13.23 %	18.14 %	12.96 %
Energy Scenario **2 A: Commercial** Energy demand 249.77 kWh/m2 annually	275 m2 (ground floor)	64 GWh annually	_	_	_	_
Energy Scenario **2 B: Educational** Energy demand 119.9 kWh/m2 annually	271.8 m2 (first floor and attic)	32 GWh annually	_	_	_	_
Energy Scenario **2 : Commercial & Educational**	528.8 m2 (the whole building)	96 GWh annually	27.44 %	26.61 %	36.45 %	26.06 %

Figure (90) : Matrix Design Calculation

8.6. Conclusions

8.6.1. Energy Data & Conclusions

Based on the matrix and the two energy scenarios, all four designs calculated based on energy production (calculation table in the appendix) and the percentage of covering the total energy demand of each possible energy scenario was illustrated in the Figure 90 .

The extra elements as balcony and canopy application have been omitted intentionally because of the small contribution to the total energy demand coverage, but they will be included in the final proposal as design elements.

As it is clear from the above calculations the roof surface is responsible for the most of the energy production. That is because the surface exists on the highest point of the building, thus with the most solar radiation, and the photovoltaic proposals have the highest efficiencies.

Furthermore, the efficiency numbers used for the calculations are the average of the matrix selections for each energy scenario. Thus, since the first scenario is more energetically demanding than the second one, the energy cover percentage for the first scenario are lower than in the second. From the above calculations it is clear that the proposals for the second energy scenario are covering more the total energy demand than in the first case. All in all, the building's energy demand in the first energy scenario can be covered by 18.14% and in the second one by 36.45% from the Design 3. That is because of the efficiency of the chosen photovoltaic modules and the color of them. In addition, the glazing have low transparency modules, which increases the energy production. All in all, the roof is the most important factor of energy production because as seen from the Figure 91, even a north-facing roof surface is producing an average amount of energy. It is worth mentioned also, that all the surfaces are not going to be connected in the same energy inverter because of different energy productions. Nevertheless, in this case, each surface with the same average solar radiation in all applicated modules should be one group in the inverter connection.

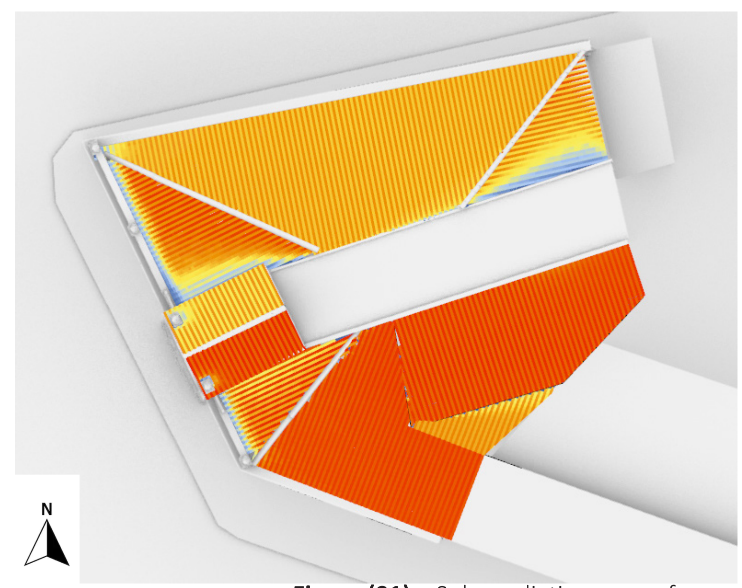


Figure (91) : Solar radiation on roof

9. Acceptability Studies


#1


#2

9.1. Introduction

Public's opinion, upon urban projects, should have valid place in the decision-making process, either it's private or public owned. This is important, because the people who will interact with this new project are those who should be convinced for the meaning of the new addition to their everyday environment. This movement is often disregarded by companies and stakeholders, especially in countries in the south of Europe, and the only permission which has some validity comes from the municipality and the local authorities for the construction of the project.

However, for this research, a public's opinion survey is going to be conducted. The reason behind this movement is the building itself, which has a great value to the city's environment but also a part of every day's life of the public. Every change in such an iconic heritage building, like the one that was mentioned in the specific research case study, would effect the way that people interact around it and, eventually, if they would agree to a change or not.

Thus, the aim of the survey is to elicit how people interact with a possible solar panel application in the heritage building "Diethnes". That means if they would agree to, firstly, a change of color, not like the one that they have used to, since it is different form the original, and secondly, if they would accept the application of solar panels, specifically designed for that building, even though there is a small difference in the finishing of the materials.

The results that are going to be produced from the survey are going to be base upon the age of the focus group. The reason behind it is that, as it is expected, the older the subjects are, the stiffer their opinion is about any change, since they have been the longer in this urban environment. However, this assumption is not binding. In addition, the survey would be mainly aesthetically, since this is the most important value of a heritage building and would make a huge impact if the new additions are not in coordination with the refurbish situation. Finally, apart from the qualitative, the quantitative aspect would also be investigated based on two extreme energy scenarios in which the design is going to be based on.

9.2. Acceptability Studies

Based on the results of the research project PVACCEPT, through a survey at the end of 2001, half of those interviewed in Italy, as well as every tenth interviewee in Germany, stated to have found the standard units placed on the market "not aesthetically pleasing" (Hermannsdörfer & Rüb, 2005). At the same time, many have expressed the view that the installation of photovoltaics was still possible in historic buildings, if the design of the technological elements was appropriately adapted. So the results of the studies confirmed this essential case. Specifically, in November 2004, it was agreed by SUPSI the significant potential for integrating photovoltaic modules in an architecturally sensitive way, not only in the new construction sector but also in existing buildings, and that potential should be exploited. Aesthetic design is a critical factor, in selling any kind of product and many consumers and investors are ready to pay a slightly more for better design and a positive image in combination (Polo López & Frontini, SUPSI).

Facing the challenge of energy transition, local energy cooperatives with their vision on energy production, have shown initiative and started changing the energy system. Based on the thesis of Mattie Jannsen, these namely are: Leudal Energie, Reindonk Energie, WIndpower Nijmegen, Energiefabriek 013, Alkmaar Energie and De Groene Reus. The number of them has grown rapidly the past five years and have a great influence on a national level. In addition, the local energy cooperatives, by involving in policy making and opening dialogues about sustainability, have influenced the political, economic, legal and socio-cultural domains (Janssen, 2018).

Furthermore, according to Frank Buchner, project leader within the Heritage and Sustainability program at the Netherlands Institute for Cultural Heritage (RCE), the awareness for solar application in heritage should be risen among citizens and municipalities and show that there multiple options in that field. In addition, he believes that the collective energy generation through cooperative solar application may be more economically acceptable from the public. He also insists that, heritage should not be a limiting factor in achieving sustainability objectives, and, since the Netherlands has 60.000 national monuments and even a greater number of protected buildings, proposes the running of a project with an energy cooperative that focuses primarily on heritage. For that to be realized though, according to Buchner, interesting projects have to put in the spotlight to attract more acceptance and investments (https://www.hieropgewekt.nl/).

For the energy transition to be realized, Dutch government challenges the citizens to cooperate actively. Based on the objectives of the government, the energy transition would not only effect the industry, but also the spatial, social and institutional fields in the society. That is the reason why the government wishes to activate citizens to become energetic, which would want to act and change for sustainability. Likewise, institutions and municipalities have to change in a like manner closing the circle. The last ones are so important to keep the enthusiasm of the citizens up, by purchasing them naturally and presenting clear information in collective local meetings. Making the process transparent by presenting a step-by-step plan and presenting experienced stories and facts, give the opportunity for a free but wise choices (https://www.hieropgewekt.nl/).

9.2.1. Acceptability Studies in Greece

Recently motives have been offered to develop renewable infrastructures, like photovoltaics, as promotion of renewable energy sources in Greece, which seems to become an important component of the Greek energy policy. However, there are environmental and economic concerns of the electricity customers as they lack of information upon renewable electricity and energy transition in general.

Therefore, several surveys have been conducted in the past few years in Greece, because there was a lack of studies upon public's awareness, willingness and acceptance of renewable energy sources in regional or national scale. The results of which are going to be presented next are conducted in islands of Crete, Tilos, Andros and in a mainland region of Greece.

All researched surveys were conducted upon different groups of people, depending on the region in which was conducted, and with different systems. However, since there is diversity in motivation and behavior of each responder, the surveyor should deal, also, with how the target group is composed and what are their specific values and backgrounds (Broström & Svahnström, 2019). In every survey there were questions about personal data and socioeconomic characteristics, like sex, age, family status, income and educational level. Furthermore, general information was asked about the respondent's environmental and energy profile and the knowledge of the use of renewable energy sources. Finally, the responders were asked about the acceptance of applicating these energy sources in a local and regional scale.

In the surveys, responders found as very important the decrease of the environmental damage of the fossil fuels, the increase of the warranty of energy supply, especially in the islands during peak hours, and the reduction of the oil dependence. Moreover, they were interested in the advantage for tourist growth through a cleaner environment, the creation of new working opportunities and the increase of life quality, on account of the reduction of air pollution. Especially, findings from the central Peloponnesus region, in Greece, the problematic energy supply stimulated higher levels of acceptance for clean energy technologies (Kaldellis, Kapsali, & Katsanou, 2012). Another interesting finding through the surveys was the fact, that people with a higher family income and higher education, who know about the importance of renewable energy sources, are those who worried more about climate change, have a "green" behavior, and are willing to pay more for the installation of renewable energy sources (Zografakis et al., 2010) (Tampakis et al., 2017) (Stephanides et al., 2019). More specifically, in the island of Tilos, around half of the responders are willing to total shift from the present fuel-based system to a local grid, that is fully fueled by renewables, and to play an active potential role as energy co-providers (Stephanides et al., 2019).

However, at the same time, responders found as disadvantages the visual pollution of the renewable energy sources, the increased installation cost and the fluctuations in their production availability. In addition, there were people that refused to pay more in a yearly basis, in order to install renewable energy sources in a regional and local scale (Zografakis et al., 2010) (Tampakis et al., 2017). In the case of south-eastern Peloponnesus, more than half of the responders are considering energy projects to be installed in their district, unless people are convinced on their virtue .The usual reasons behind this behavior was the belief that renewable installations had to be built with the taxes of the Greek citizens and also that they were tired of paying more services related to the Public Power Corporation (Zografakis et al., 2010). Furthermore, it is a great finding that the public expects more interventions of the State and more true objective information from the Mass Media, since information for energy savings through special brochures is slightly satisfying, based on the survey in Andros (Tampakis et al., 2017). Thus, public objection has been widely discussed as an obstacle to sustainable energy interventions (Stephanides et al., 2019).

It is observed that, developing a renewable energy project near a community, occasionally, causes the locals to react negatively with suspicious feelings about these types of applications in their neighborhoods (Walker, Devine-Wright, Hunter, High, & Evans, 2010). And that is because, the public concerns often is born from the fact that environmental advantages of renewable energy sources projects are realized on a global or national level, while, environmental impacts of such systems only influence the local environment and residents (Stephanides et al., 2019). In some cases, such

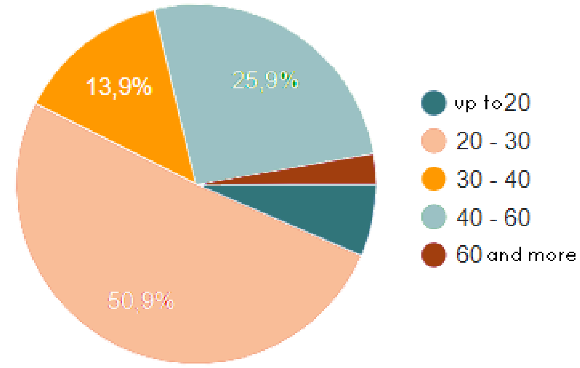


Figure (92) : Age of responders

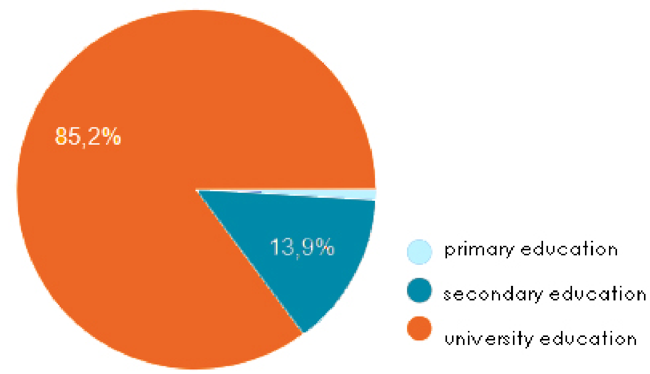


Figure (93) : Educational level of responders

concerns affect negatively or even obstruct the realization of renewable projects. A representational example is that of a Greek island, Euboea, where almost 200MW of wind farms were placed until 2001 and the opposition to the project led to a paused plan still not completed (Kaldellis et al., 2012).

9.3. Conducting the Questionnaire

The used sampling method, was a simple random sampling, due to its simplicity and because it required the least possible knowledge of the population compared to any other method. As a result, an online questionnaire was designed in Google Documents in order to be accessible from every media. The questions that were selected were upon the color of the building, the acceptance of the photovoltaic application and the reason why the public would accept this change in such an iconic building for the local community. Nevertheless, this action could be expanded for an other research in order to investigate the energy transition in the area and how willing is the public for that change.

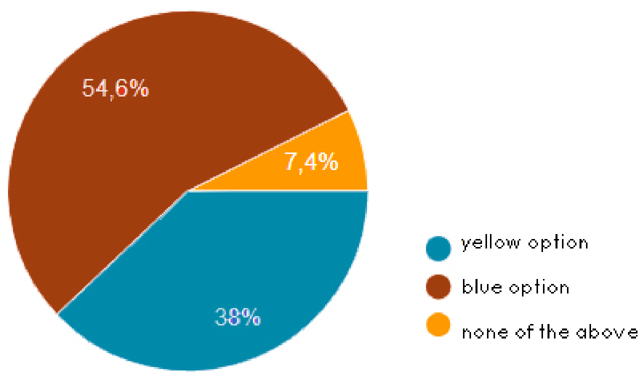


Figure (94) : Choice of color

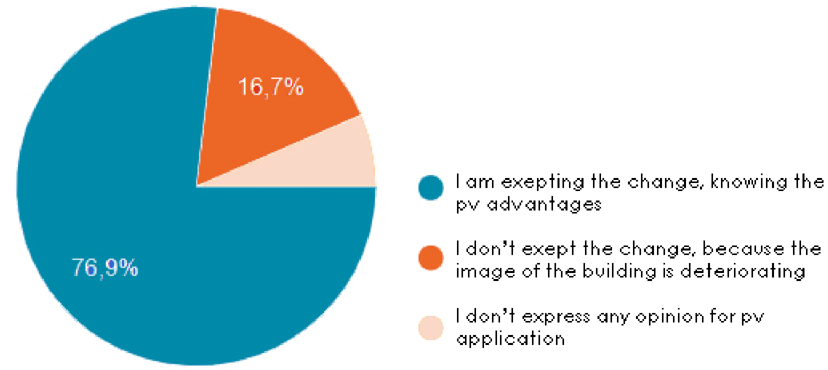


Figure (96) : Opinion on pv application on the building "Diethnes"

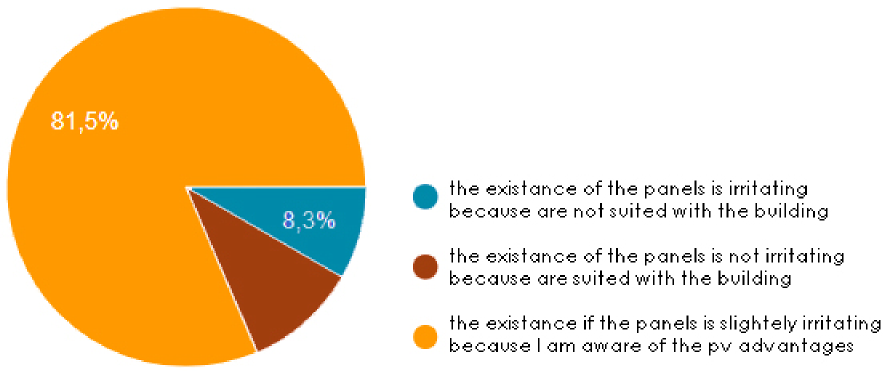


Figure (95) : Opinion on pv application on a random building

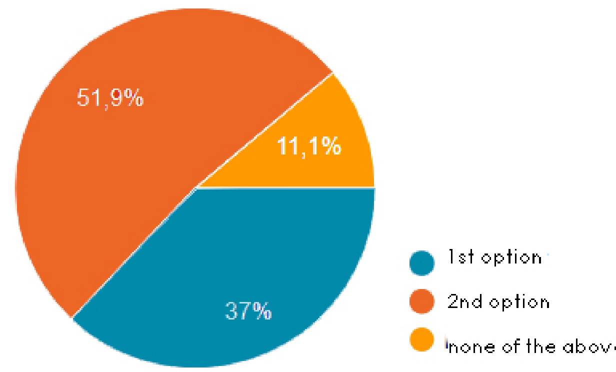


Figure (97) : Choice of building's color

9.4. Results of the Questionnaire

The online questionnaire was filled by 108 people of all ages: 50.9 percent are between 20 and 30 years old and 25.9 percent are from 40 to 60 years old (Figure 92). The educational level of the applicants was asked in order to detect any ignorance level related with the answers, but 85.2 percent of them have university studies done and 13.9 percent have a secondary educational level (Figure 93).

Almost all the applicants knew the existence building, as it is a landmark for the city, and so, 96.3 percent wished to be renovated and be included in the functional urban environment. Because of the building's importance, it was inquired if they knew that the building was another color from the current one, and 79.6 percent responded that it was not known . The question about the color was vital for the end results, because a change photovoltaic color changes automatically the efficiency of the module itself. It was very surprising that even the current color of the building is yellow, and the public is familiar with this certain building environment, 54.6 percent of the responders are willing to return to the first color, which was the indigo blue (Figure 94).

As for the photovoltaic application, most of the responders are informed about the production of electricity and hot water from photovoltaic application. With that said, it was presented to them a picture of a random building's roof with unintegrated photovoltaic modules and it was asked to respond to this. The answer to the question was that 81.5 percent of the responders didn't bothered form the existence of the panels because they knew about the positive effects of photovoltaic technology (Figure 95). In addition to that, an other picture of the building's model was presented with familiar solar modules, which was applied based on the building's radiation map. The outcome was that 76.9 percent of the applicants accepted the change because of the advantages of photovoltaics. However, 16.7 percent did not accept the change because it would change the building's appearance (Figure 96).

Furthermore, a detailed image of the emergence of the modules was presented and the applicants were asked to choose one of the two colored options, or none of the above. From the responses, 51.9 percent chose the blue version of the building and 37 percent the yellow one, while 11.1 percent didn't want any change (Figure 96). As a follow-up question to the previous one, the applicants were asked to express their opinion on the contrast of the module's material from the plaster and the glass-finish. The answer to that was that 59.3 percent noticed the difference of the materials in a closer look but that didn't affect the total appearance of the building. In addition, 21.3 percent of the public noticed the polarity and their opinion was that changes the total appearance of the building (Figure 98).

Last but not least part of the questionnaire, was the module choice for the roof, since it holds the highest merit of the total envelope surface and becasue it is in the highest position of the building receives the highest solar iradiation. Six options were presented, based on shape and color, three panels and tree tile modules with grey, blue and terracotta-like color. The responders were asked to choose one option from every color. In generall, the tiles were prefered from the responders than the panels. Between the tile selections the blue and the grey had higher votes. It was surprising that in the terracotta option 55 percent chose the tile rather than the panel, a number with a small difference between tile and panel, but overall had the lowest request, in the tile option (Figure 99). As a follow up question, it was asked from the responders to justify their opinion. Most of the answers were based upon aesthetical

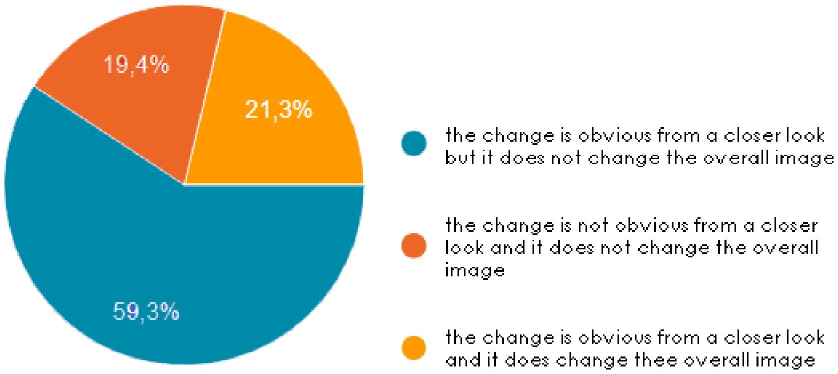


Figure (98) : Opinion on the material differemce

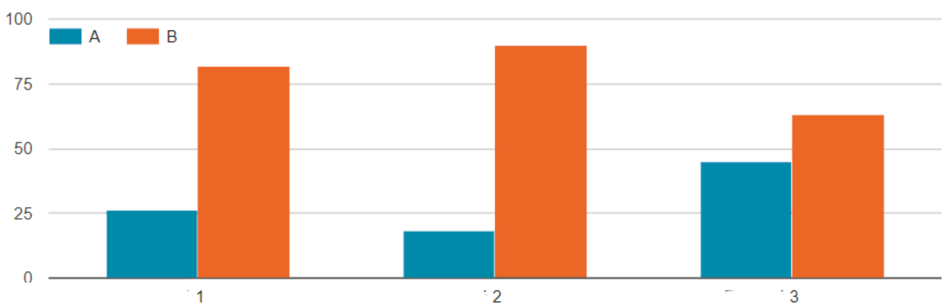


Figure (99) : Opinion on roof options

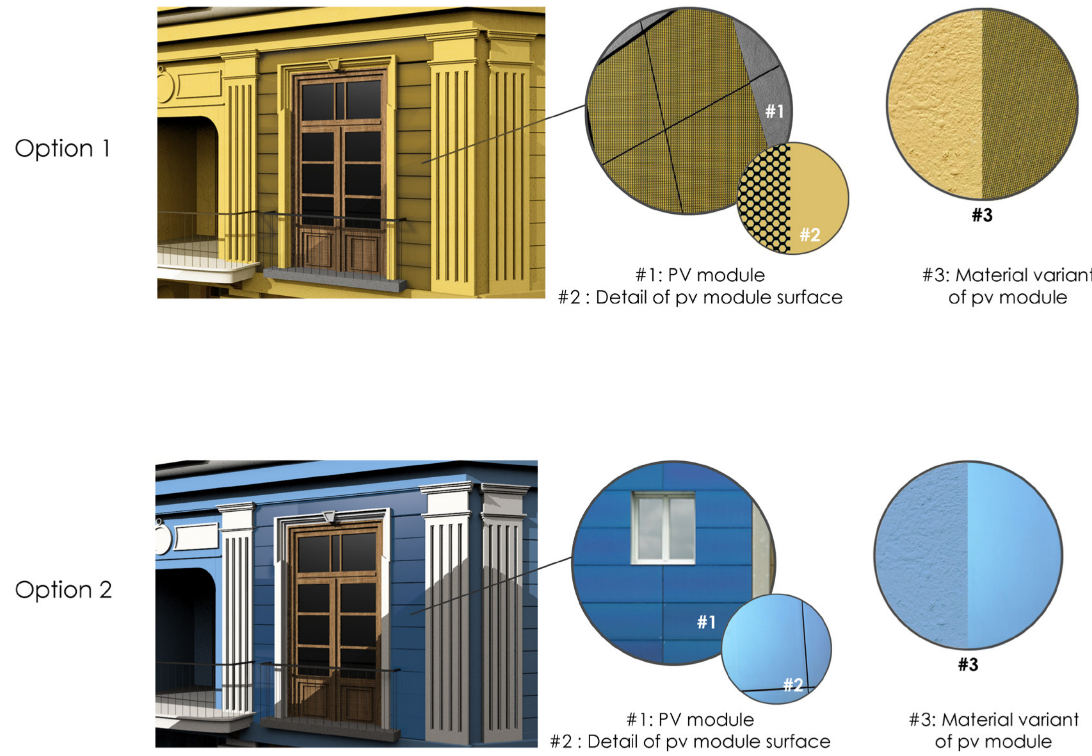


Figure (100) : Options on plaster application presented in questionnaire

reasons and how well would the panel be integrated in the roof and with the urban environment. Imitating the existing roof tiles was one of the greater reasons for their choices. There were some answers related to efficiency and cost. Only one answer was completely opposite to any aesthetical intervention, even for energy-related reasons, and the applicant was chose to answer in a hypothetical scenario, as it was written in the description box.

9.5. Conclusions

Both in terms of cultural heritage preservation and energy efficiency, any change to a certain urban environment has to be accepted form the majority of the local community and from local authorities. An early stage dialogue between the buildings control and the conservation authorities is needed and all the sectors involved in a renovation project (Polo López & Frontini, SUPSI).

Since the urban environment is consisted of heterogenous constructions, which have to fulfil different needs, aesthetic and technical issues, it is important improving solar systems acceptance by the residents, architects, planners and representatives of monument protection authorities (Polo López & Frontini, SUPSI). All the energy efficiency melioration measures, by renovation, restoration or rehabilitation of these special buildings, that have been studied ,are focusing at maintaining and protecting the original architectural elements strengthen the historic charter and increasing property worthiness while avoiding deterioration (Polo López & Frontini, SUPSI).

The survey which was conducted in the local community for the case study building “Diethnes”, was enlightening to the acceptance of renewable energy sources in the urban environment. Since it was address to a small local community with high protection upon heritage culture, the results were very different from expectations. In fact, the knowledge for solar energy and the acceptance of its application, was zestful. In addition, a surprising outcome from the responses was the willingness to compromising the aesthetical aspects for energy reasons. The feedback after the end of the questionnaire was also unforeseen. People reached back in order to learn more about these solutions, their efficiency and cost. Furthermore, they were impressed by the extended variant of photovoltaic technology, which, due to economical crisis, the energy transition in Greece is following with a slower pace.

Due to misleading perceptions and information gaps in the field of renewable energy sources, general public and decision makers have drawback on investing in those. The above acceptability studies and surveys prove that high awareness levels and energy reliable behavior for energy saving, are linked to positive notion and disposition for renewable energy sources. Thus, it is vital to increase information awareness activities towards energy production from renewable sources, biomass, biofuels and bioclimatic technologies, active and passive, to put over the best results in realizing renewable investments and, also, in a gradual energy transition. Generally, the conclusions of the acceptability surveys could form an important tool for the policy-makers and would effect their decisions on local and national level.

These campaigns should not only linked to the general issues, like climate change, but also to the local specific circumstances, like tourist development and security of energy supply of insular regions. Moreover, education could play a significant role formulating an energy-related, environmental behavior (Ntona, Arabatzis, & Kyriakopoulos, 2015). By focusing on the knowledge, disposition and behavior of students, shaping the future generation is achieved. According to Zografakis, raising energy awareness and providing subjective information tend to converting the passive consumer into a accountable and active citizen who will participate in forming the energy and environmental future, and become an active member to energy transition. (Zografakis et al., 2010).

10. Design Proposal

10.1. Introduction

In order to decide which modules are suitable for the design proposal all aspects had to be revised. Key points from literature research and governmental guidelines are the milestones for the decision making. Nevertheless, the criteria derived from the case study of the building "Diethnes" itself and the public's opinion upon the photovoltaic application, play an equal role to the final proposal. Redesigning the image of a heritage building by solar module application is a complicated decision, since many factors are equally important for the final result.

The following design combination is proposed in order to improve energy performance of the building, targeting the energy production by photovoltaic module application on roof and façade, south-west and south-east. The application is going to be performed together with the assumed renovation of the building, since the solutions are technologically advanced, and the final calculations are going to be performed in an energy efficient canvas. The design proposal, so, it is going to be divided into sectors of application in order to clearly justify every solution chose. Finally, the complete image of the building is going to be evaluated and the impact that the change has to the urban environment.

In addition, referring to proposed energy scenarios, there are advantages and disadvantages in both selections. The energy demand of each scenario is a product of high-end interventions on the building based on Greece's Energy Efficiency Regulation of Buildings (KENAK), such as insulation, aluminum frames and double-glazed windows. If the function of the hotel is chosen, to wit, the proposal with the highest energy demand, could attract investors in order to fund and profit for its operation. At the same time, due to seasonal tourism, there is the possibility of vacancy in autumn and spring. The vacancy derives from the fact that the city is a destination for the winter because of the near ski center, and a summer destination because of the cultural festivals. If that is the case, the vacant months could be used as dwellings, in order to operate all year long. On the other hand, if the multi-function use is chosen, that is to say, the proposal with the lowest energy demand, it could be all year operational by inviting more educational clubs to join the program. However, the clubs could not invest in the renovation and the application of the solar modules, so the authorities and the owners should find a solution funding the project. A possibility to accomplish the latter, would be the funding from foundations and known cultural centers or funding from European Union's programs.

Thus for the proposed design, a combination of the two scenarios would be the golden mean. The recommended combined function consists of commercial function in the ground floor, and hotel in the first floor and attic, such as the style bed-and-breakfast, in order to have a yearly function.

10.2. Application sector : Roof

The roof of the building holds the largest surface in the building. Even if the volume is not too high, the height of the surroundings helps to access sunlight all year long, and thus, to be energy productive.

There were some restrictions based on the module variety, especially in the combination of color, shape and efficiency. There were companies that were flexible to size and color but there was lack in efficiency and shape, such as the printed panel or the dye encapsulant solutions, and others that had the desirable shape, but either there was lack in efficiency or the color, such as the terracotta tile with photovoltaic cell ore the waved solar cell by Hantile.

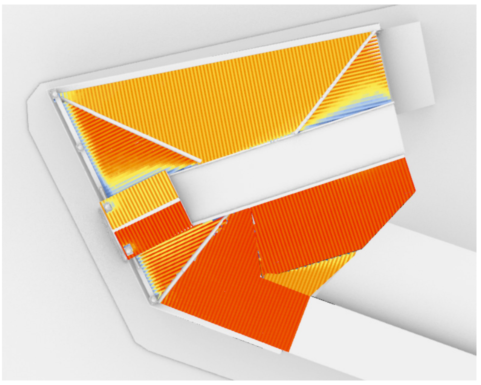
There are different possible solutions for the roof. From the matrix was concluded that not all the modules are producing the same amount of energy. In addition, the bigger the module the less percentage of roof coverage (Figure 101). Thus, small modules are more suitable in this case, since also, the roof is a combination of sloped and flat surfaces. But, also between the tile shaped and sized modules, the coverage is different because of the area of each module.

Based on the design requirements, the perfect combination would be the waved solar cell in a terracotta-like color. The wave shape is in accordance with the existing roof tile and has relatively high efficiency in energy production. However, due to the fact that this particular module is produced only in grey and deep blue version, this selection is not possible. That said, the selection that is proposed is the terracotta tile attached with the solar cell by the company ZEP Solar and the product name is Nibra F10U Redline, in the color Natural red (Figure 102).(https://www.zep.solar/nl/)

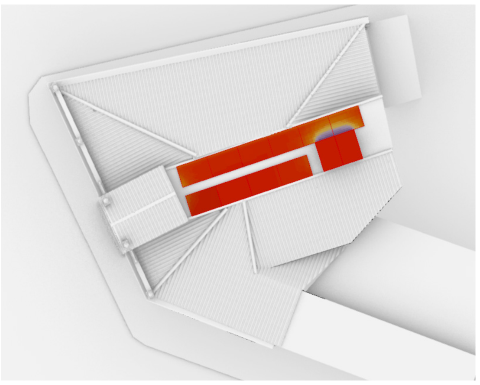
This particular module is one of the most adaptable innovations in the field of integrated solar energy modules. The solar cell tile consists of a highly watertight ceramic roof tile made of pure Westerwald clay, with a natural red photovoltaic module in the same color as the pan integrated into it. The result is a product of a patented process that gives the solar cell its natural red, terracotta-like color. A traditional heritage orange roof thus becomes an energy roof generating its own energy.

The clay comes from the west of Germany due to its properties, specifically due to the pureness the capacity to be baked in high temperatures, and the tiles are produced in the Netherlands. The baking gives the tile its final, natural red color without the addition of pigments making it very color-cast. In addition, the company promises that in their product quality standards and controls are being strictly applied. This solar cell roof tile is also produced with ventilation standard specifications, so there is no risk of ventilation problems or overheating. The roof tile is produced in collaboration with Nelskamp Dakpannen.

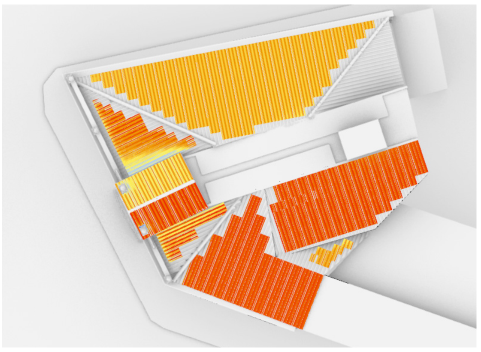
The product is suitable for the case of the building "Diethnes" due to the fact that the size can fit every part in the roof, because of its division into multiple parts. Furthermore, the color of the tile imitates the terracotta-like color of the original tiles and respects the tiling lines by producing the wave effect on the roof. What is more, the colored module on the tile has exactly the same color with the base and that makes it difficult to distinct from a long distance, such as street view or higher building or landscape, and has no reflectivity. That being said, the whole roof could be applied with this type of module and, even if the whole tile is not operational, where would be no issue to install the tile in every part of the roof due to its size (487 x 296 mm).



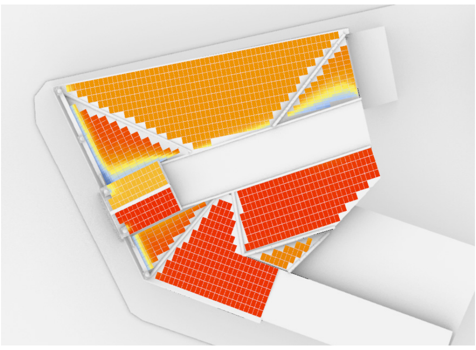
Total solar radiation of roof sloped surfaces



Slate modules in flat roof surface (Colorblast)



Wave modules in flat roof surface (Hntile style)



Slate modules in sloped roof surface (tile cell)

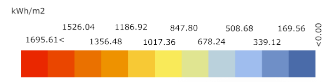


Figure (101) : Solar radiation analysis on the roof (Grasshopper&Ladybug) _ Variety of modules

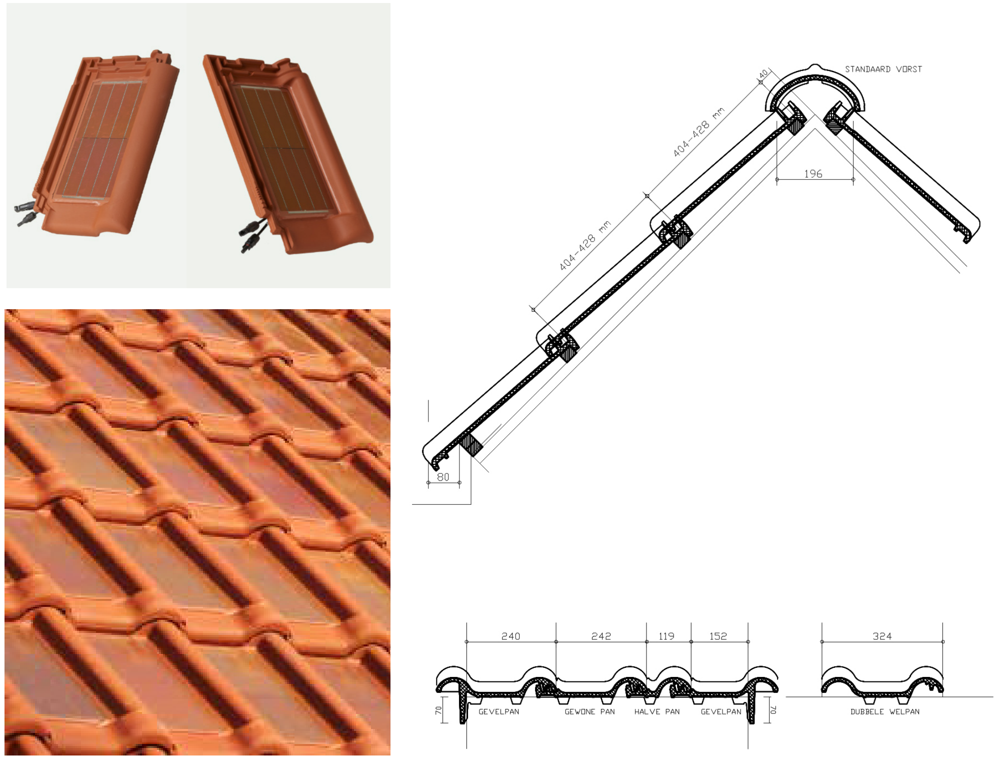


Figure (102) : Roof Details (https://www.zep.solar/nl/)

Figure (103) : Main elevation and view from street

The flat part of the roof could be left as it is or covered with flat modules in grey color without reflectivity that could match the concrete that already exists. The size of the surface could fit six large size modules. This part has all year sunlight with the high radiation because is completely flat.

The part of the roof that do not have enough sunlight to produce energy, and these are the blue parts in the roof of the solar radiation map (Figure), could be covered by a traditional tile which follows the same shape and size as the one with the solar panel in order to have a uniform image from a bird-eye-view. In addition, these part of the roof are only visible from certain higher buildings in the north of the site and thus is not noticeable from important viewports.

Figure (104) : Solar radiation analysis (Grasshopper&Ladybug)_Fragmented surfaces

10.3. Application sector : Façade

Although the roof is not visible from street view, except the part in the triangle pediment, the façade of the building, especially the south-west and south-east part is the building's iconic image and plays an important role in setting the scenery to the local urban environment in the city of Florina. It is not only its style but also the history that holds. It could be said that these faces are the most important in the building. In addition, the location of the site is such that the views are visible from important viewports in the city's grid (Figure 103).

Based on the solar radiation analysis for the facade, (Figure 104), the fragmented parts that frame the windows on the first floor recieve an average solar radiation annually. That is the reason why the module application is going to be placed based on the solar radiation map (Figure 104). Consequently, the places on the façade where modules could be placed are the surface between the windows and the pseudo-columns and the crown. In addition, more elements could be added in the shutters, balcony, windows and in the entrance as a sign . Every other application is not recommended by the solar radiation map calculations and also is going to deteriorate the architectural character of the building. Thus any extra intervention is not possible.

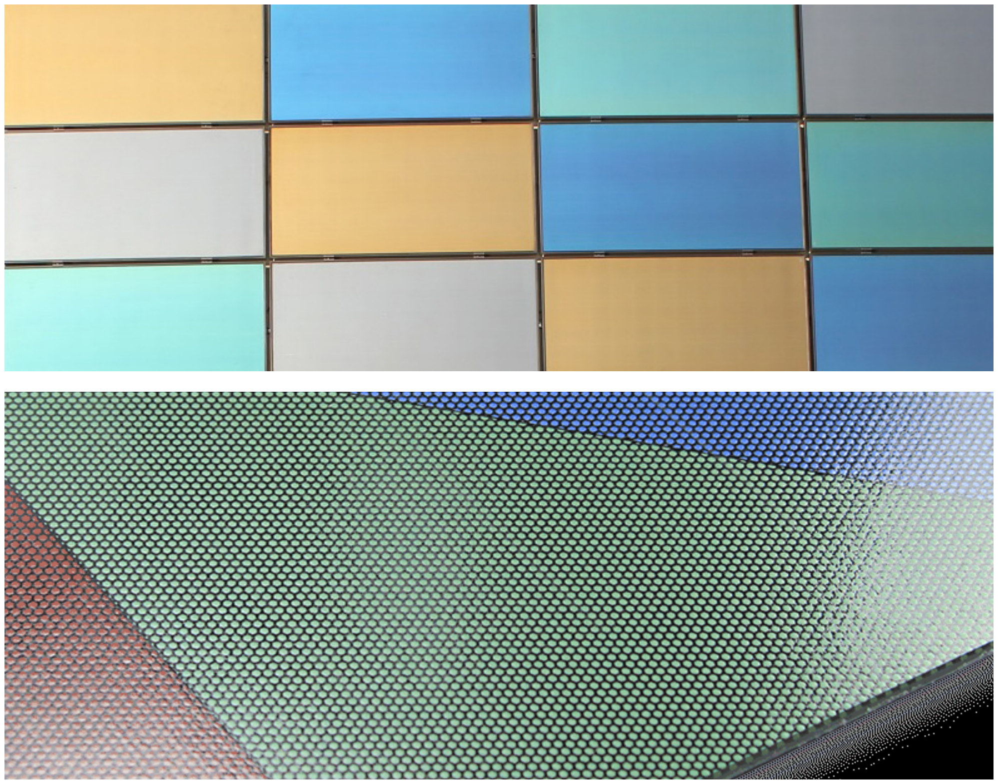


Figure (105) : Kameleon modules_Kromatix (up) and Coloblast (bottom) (https://kameleonsolar.com/)

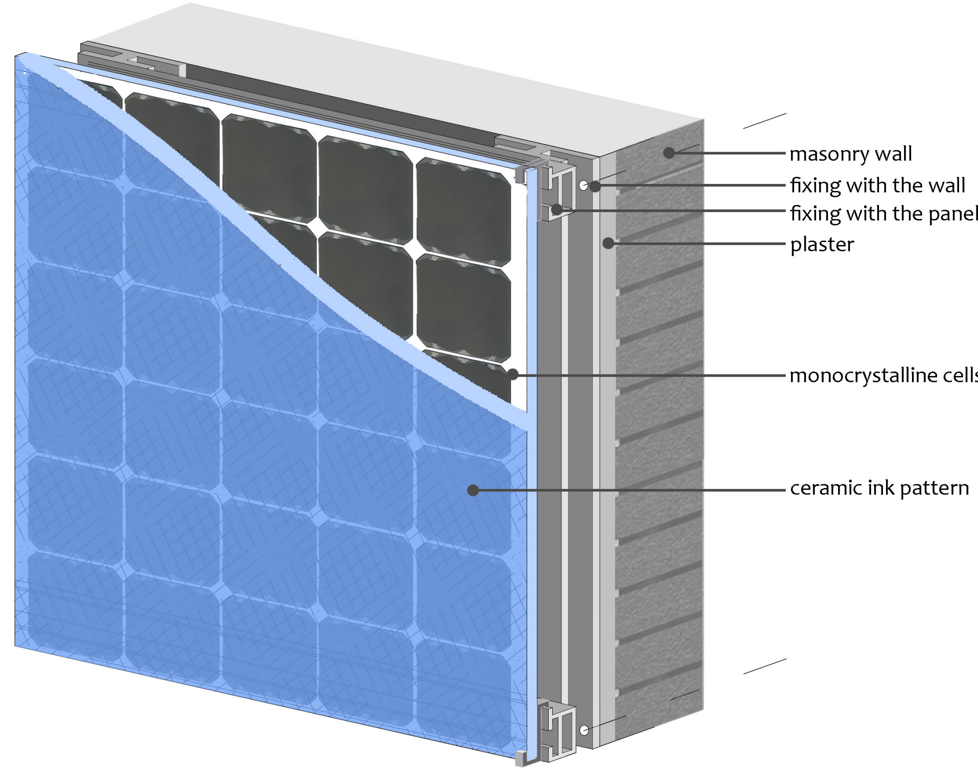


Figure (106) : Detail_Photovoltaic Application on Facade

That said, the choice of the photovoltaic module recommended for the façade should conform to certain guidelines and color scheme. As far as the latter, the color scheme in the current situation is different than it is used to be, specifically from indigo blue that one was to ochre yellow. Based on the guidelines and authenticity regulations, if the building would be restored, it would return to its original color, and that is the indigo blue. Furthermore, in reference to the questionnaire answers, the public agrees to the change of color into the older version, making then the decision even more definitive. This version of the façade scheme consists of the use of indigo blue in the bare surfaces between the pseudo-columns and window frames, and the rest decorative elements would be in white, following the example of a recent building renovation in the same style.

10.3.1. Fragmented surfaces

The photovoltaic modules which are recommended for the surfaces between the windows and pseudo-columns are by the company Kameleon (https://kameleon-solar.com/). There are two lines in the same company that are suitable for the case study, Kromatix and ColorBlast (Figure 105). Kromatix is a Swiss solar glass innovation by SwissINSO. These modules are custom-sized colored solar panels, available in six unique colors, one of the blue that matches the chosen color of the building. Each color has high light transmittance, which makes this color option the most efficient in the range of the company. However, Kromatix modules seem to change in color, based on the viewing angle, and hiding the solar cells beneath. The module's color is not made by dyes or pigments but from a coat of coloring inside the module which will not fade in time as the previous options. In comparison with the other line of the company, ColorBlast, in which the modules are coated by color pigments in a pattern in the outer layer of module's glass, the two options have the same power efficiency, around 130 Wp/m2, due to the color. The disadvantages in the option of Kromatix, is the change of color by changing the sunlight and the view point, and in the option of ColorBlast, is the pattern and its density that could change the color shade, referring to the original, and it could fade by time since exists in the outer layer of the module. But since it is vital for the elevation of the building to maintained the same at all light intencities and city viewports, Colorblast is the choice for this case. Moreover, as the color fades, so does the paint of the plaster, and thus they could age with about the same pase.

The installation of the modules is another essential element that influences the end proposal. Since the distance from pseudo-column to pseudo-column is not far and varies from repetitive unit to unit, as it was described in the matrix, the modules could be installed in two different ways: as one extra-sized module as an extra frame to the window with, or as pieces following the lines of the surface (Figure 106). In both cases, the lines of the surface should be emphasized because are features of the building's architectural character. Therefore, in the first option, the lines should be emphasized in the color injection by printing a more dense pattern in that area, and in the second option the distinction is obvious since the structure of each module is separate, and the modules are parallel to the surface. To sum up, the option of individual modules is more well-suited to the case study, and thus this is the proposed one on the final design.

Figure (107) : Main elevation and view from street

The selection was made by the level of dynamism of the façade, and thus, ColorBlast is proposed because does not change color while the sun path changes, which gives the same image both in summer and winter time. In addition, the modules are custom made and could be in the exact same color with the façade in the shade indigo blue. Nevertheless, there is always the color-fading scenario in time, but the plaster is going to change color too because of the deterioration and by the time of repainting the building the modules should be changed too due to efficiency drop.

The top part of the building in the roof's foot, the crown, there is also bare surface with relatively medium solar radiation, as the rest of the façade. Because of the white color of the crown though, only a white colored or transparent module can be installed, though both have very low efficiencies. Nevertheless, a slight change could happen by changing the color of the module for that part and trade it with a blue one, just like the first floor outer surfaces but in an other size. This change, is possible because is included in the building's color scheme and does not effect the character of the building. Besides, the color proposal is based upon a recent restoration of another case, which does not happen to have crown, and so until the color of this particular crown part is declared white, it can be assumed that a blue option could be equally accepted (Figure 107).

All modules selected can be produced with textured glass as a final surface in order to blend in easier with the existed materials, i.e. plaster, and to avoid glare.

The mountaining of the installation is going to be a typical one, in other words, drilling right through the wall, because the important part of the heritage building in this particular case is not the materials, but the image of the building itself. Thus the opening on the outer walls can be repaired if the module removal is in need.

10.3.2. Window glazing

For the window glass there are not many variants that are suitable for heritage buildings. The options of crystalline cells encapsulated between glass, responds to a progressive scenario because it creates a pattern in the widow surface. However, if the crystalline color is grey and the distance between the cells is not much, the window surface has a greyish overall image and a low transparency to the inside, which gives the illusion of a homogeneous end result. That solution is higher is efficiency, rather the transparent options, and is proposed to be applied in the ground floor upper windows, because their purpose is only referring to the style and are above human height, and so human direct eye contact. For the rest of glass surfaces on the ground floor, no photovoltaic addition is going to be performed, since there is low solar radiation and the transparent modules are low in efficiency.

For the windows on the first floor, an element of identity is possible to be applied without compromising the architectural character of the building, and even more enhance it. The proposal is about stained photovoltaic glass, which is produced by amorphous silicon in a huge variety of colors, which can produce energy, for example for charging a mobile phone. The efficiency is still low, however, presents the different solutions of energy production in an artistic interesting manner (Figure 108). For the rest of the windows, no additional photovoltaic application is recommended because of the low efficiency and high cost of transparent modules, and because these windows are cover by shutters, in which solar cells are being recommended.

In the renovation process, there are two possible solutions to window treatment. The

Figure (108) : "Stained glass" by PV_First floor winodw glazing

Figure (109) : Solar radiation analysis (Grasshopper&Ladybug)_Shutters

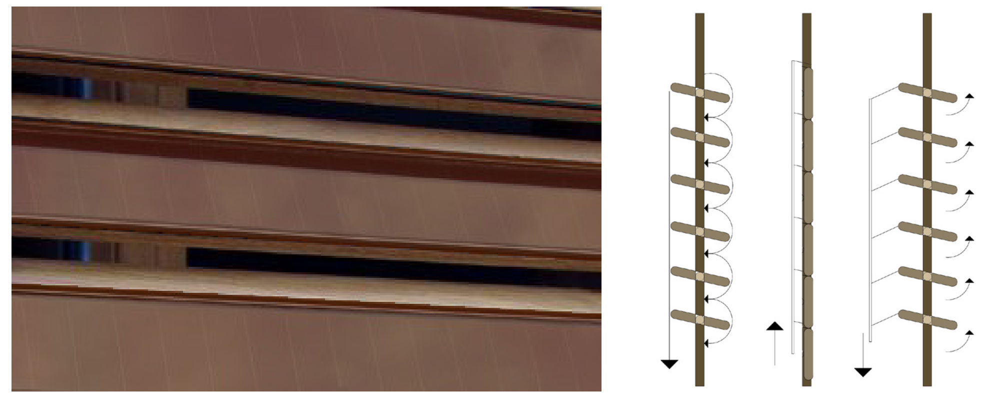


Figure (110) : Thin film bi-facial photovoltaics in the color golden brown (left) and themovement of them (right)

first one is a double layered window, where the original one is refurbished and left untouched, while in the second case, the window itself is being replaced by aluminum frames and double-or triple-glazed surfaces, in order to ensure minimum heat losses . In the case of "Diethnes", there is the assumption that because of the renovation, all window frames are being replaced by aluminum windows with wooden appearance, to simulate with the original ones, and with triple glass to assure minimum energy transition.

10.3.3. Shutters

The French shutters are an additional element of the building, which all buildings in the same style owns them. However, the recently renovated case of "Florian", omitted the shutters of the previous version of the building, but as it seems, it is a decision based on the new function of the building, which from dwelling that was before, now it is used as a café, and thus the shutters are no longer needed (Figure 62).

In the case of "Diethnes", since the upper floor is going to be function as hotel, then the shutters should not be omitted, due to the fact that the residents should be able to regulate the solar radiation which inserts the room. From solar radiation analysis on the shutters, found that the louvres have high solar radiation intake, and thus are suitable for photovoltaic installation. (Figure 109) For this application, is suggested the modules to be thin-film strips in the size of the louvres and color which adapts to the color of the wood, brown (Figure 110). There are two ways of installing them: the first one is only in the outside surface of the louvres, or as a second case, in both faces. The second option could also be replaced by bifacial thin-film photovoltaic strips, but this innovation needs further research and development. The application of the double-faced photovoltaic louvres is effective as it can produce energy in multiple ways. When the shutters are completely closed and there is direct and/or diffused light from outside of the building, the photovoltaic louvres could work in with high efficiency (Figure 110). In a night condition, there is diffused light from the urban lights and direct light from the lightbulbs inside the rooms, and also in this case the strips could work with a medium to maximum capacity (Figure). Finally, when the louvres are opened, their inner side is exposed and could produce energy with high efficiency .

All in all, because of the small surface in total, the percentage of energy production in the total energy demand would be small. Though, it is a great addition and if the thin-film technology develops higher efficiencies, the contribution to the energy balance could be more.

Figure (111) : South-west facade elevation from street viewport

10.4. Design Proposal Overview

The final design is proposed based on the design requirements from literature research, reference case studies and the building's own requirements. These proposal is a possible option derived from the matrix and the four designs which have been researched and calculated. The base for the proposal was the solar radiation analysis through Grasshopper & Ladybug, and the final energy production has been calculated.

The choices for the proposal are : terracotta-like tile in the sloped surfaces of the roof (energy production: 19.9 GWh annually) and grey panel type Colorblast in the flat part of the roof (energy production: 3.4 GWh annually), amorphous silicon modules for the window glazing in the upper part of frames on the ground and first floor (energy production: 0.23 GWh annually), ceramic ink pattern panels in the color indigo blue type Colorblast (energy production: 2.18 GWh annually), and thin film bi-facial modules in the color golden brown for the shutters (energy production: 0.85 GWh annually). For the balcony, no change is recommended because any intervention changes the final image of the building. All in all, the design proposal of solar intervention is producing 26.56 GWh of energy annually. Considering the energy scenarios proposed for this building, the produced energy is the 13.76 % of the total energy demand in the energy scenario of hotel, and the 27.66 % of the total energy demand in the multi-functional energy scenario. That variant exists because different functions have different energy demand.

To sum up, the major interventions are proposed for the roof of the building since the roof holds most of the surface and in a preferential position. The size of the module was vital for the highest capacity of energy production from the roof surfaces. Thus, the smaller the module the higher the percentage of coverage. Nevertheless, the final size should be close to the original tile if imitating the original version is vital, which is in this case.The choice of the tile could be defined as conservative due to its color and the intervention is following suitable guidelines for heritage buildings. In addition, the roof with this color could easily blend in to the urban environment and to be accepted more easily from the local community.

The façade interventions could be defined in a state in between conservative and progressive. That is because the intervention itself is a major change in the main elevation of the building, when the public has an other image for the area but could be considered prudent since that was the first color of the structure. Furthermore, the additions on the plaster, the window glazing, and the shutters are more to the progressive site, since the facades are the dominant element of the building. Yet, the selection of color scheme, the sizing and shape and the texture of the modules are aligned with the design requirements.

In parallel, a potential critical point could be the alignment of the south-west with the north-west façade, as in the first one the installation exists and in the other not. The more visual differences could be in the ground floor windows because these are the most extreme intervention proposed. The plaster replacement and the shutters are considered minor since they follow the existed color scheme and texture of the original material.

Worth mentioned, regarding the application itself, no additional surface was created.

All modules have been proposed to be placed parallel with the existed surfaces in order to correspond with the building's lines. In addition with the proposed color scheme and the module's outer surface structure, all lead to a proposal that "camouflage" the photovoltaic application for a maximum integration to the building environment and the authorities' and public's acceptance.

At the same time, because the suitable surface for photovoltaic application is very limited in order not to deteriorate the architectural character of the building, the façade interventions could be omitted, as they provide only 2 percent of the total solar energy production. However, the technological developments will be continued and in a scenario which, in 30 years from the application the modules should be replaced because of low capacity, then there will be the base and research to install new modules, with other features and continue the vision.

As a whole, the proposed design is achieving two targets. The first one is to maintain the old glory of the building and protecting its heritage and history, and the second one is to include this category of buildings into the energy transition movement and prove that if rules could bend, the value of what is produced is going to remain for the next generations.

10.5. Discussion

The study shows the potential of a heritage building to adapt to the energy transition, and more specifically to the energy production of solar technology. The aim of this research paper was to answer the following question : " How could photovoltaic technology be applied on heritage buildings, without compromising their architectural character ? "

In order to answer this main research question, a literature research should be made upon regulations, guidelines and similar cases, in order to reach to certain design requirements for the final design proposal. Through the literature review, guidelines from different countries and conventions gathered to find a common place. In addition, similar case studies evaluated based on the criteria found in literature and new guidelines were formed, more extensive and precise than the latter.

Through research the possible suitable solutions for heritage buildings were gathered and characterized based on the criteria which were previously defined. In addition, the energy scenario selection was an important part of the final design proposal, since the produced solar energy could be placed in energy balance and gather as much information as possible for a feasible solution.

The study was conducted considering that renovation process is in parallel path with solar application. Because, in order to provide energy production options, first and foremost, the energy efficiency of the building should be succeed. Nevertheless, all the different design parameters described in Chapter 8 should be adaptable in other similar heritage cases as well or could act as inspiration for interventions in other architectural heritage cases.

11. Conclusions & Recommendations

11.1. Conclusions & Recommendations

The topic of my graduation thesis first started as a question of how photovoltaic technology could be applied on heritage buildings, without compromising their architectural character. Giving a simple answer to this question, is that the photovoltaic technology could be applied on heritage buildings, by following regulations and guidelines from cultural authorities and customizing the modules to each case in order to be excepted from the old structure. However, the answer could not be so simple, because of the way that these rules could be applied in each case scenario, and depending on the end result that the architect or/and the consultant wishes to produce. Together, with all the different varieties of products which exist on the market, and others that are still in development process, complicates the possible design solution even more.

Following by the main research question, there are sub-questions regarding the application of photovoltaic module in general, the evaluation of reference cases and the design proposal.

From literature research, the most suited places to integrate photovoltaic technology on heritage buildings are façade and roof. However, the characteristics of the module itself and the design requirements from the building case, create a unique combination, since every case is unique. The methodology for photovoltaic application can be followed but the end result is going to be different. Only in cases that they have similarities, like the architectural style, could be proposed the same approaches, but since the building would be different, so would be the end result.

The criteria for evaluation a photovoltaic application on heritage buildings can be divided to objective and subjective. The objective are implying to the building's architecture and the subjective to the viewer's opinion. The objective criteria are vital for a successful solar application, but the subjected can be never be on the same page. Nevertheless, the approval from authorities should have a bigger importance but also the public could be included to the process in order to familiarize with the intervention.

About the design proposal, it can be concluded that there is never one solution to the puzzle. From matrix is clear that different combinations produce different results and the outcome can be judged based on the above objective criteria. However, the final proposal for each time has to conclude the function of the building and the way that is going to be reentered into the urban environment. Thus, the photovoltaic application can be versatile.

The limitations to the design are based upon the authorities' guidelines and the building's special requirements.

Regarding the solar modules, the variety that exists o the market and on the lab is huge but sometimes, especially in cases of heritage buildings, some characteristic combination is missing. The most suitable photovoltaics are those which imitate the case materials and thus blend in color and size with the original parts. These are the elements of a design which do not decrease the original architectural character, but at the same time increase the assessment value of the building itself.

Last but not least, public's acceptance of sustainable interventions has been found very diverse, from the point that the negative opinion does not affect the decision making, to the point that projects pause for an indefinite time period due to protest. However, form the acceptability studies and questionnaire, people are familiar with new technologies and, basically, due to economically reasons, the have the intendency to reach for sustainable solutions even if they are not pleasing on the eye.

That being said, with a logical and step-by-step methodology, it is possible to convert all the above variants in our interest and produce different options based on different energy scenarios. The end result could not be only one and is depending upon the designer's wishes

11.2. Limitations

First of all, the basic omittance was the building's renovation plan, since the deterioration is progressive and thus that would be the first step to change the energy demand of the building. Regarding the project's uncertainties, the exact energy efficiency of the photovoltaic modules is unclear, since the weather conditions and the color could change the energy performance, and so the energy production. In addition, the companies did not share every detail of the conditions in which these modules performed better.

The limitations involve the final design proposal. Since it is a heritage building, any possible intervention has to follow many guidelines in order to be approved. Greece's regulations, and generally from the Mediterranean countries, in particular, are anachronistic and retrograded, in comparison with other countries in the European Union, and in addition with the bureaucracy, decision making for heritage buildings is very difficult form every point of view. In this case, the drawings that were given to me, were not up to date and the new version was not existed. Thus, in order to proceed with this case I had to survey the building and produce new versions of drawings.

11.3. Further Research

All in all, technology is progressing with big steps and innovations that were part of science fiction, now are vastly used. For that reason, solar technology is advancing everyday and new possibilities with higher efficiencies and lower size and weight are being invented. Regarding specifically the building sector, there are more modules every year, more advanced and efficient. In addition, by evolving the modules surface structure and colors, it is a way of attempt imitating original materials. In some cases the researchers try to combine the advantages of an original building material and a solar module in order to make hybrid that has the advantages of both structures and to act as one construction.

At this time the market has a variety of different modules and even those can be customizable if a large and important project occurs. However, regarding the solar interventions in the heritage sector, a module which could be imitate exactly the form of a terracotta tile was missing. The combination of a "wave" shape, the terracotta-like color and the rough matt surface, is not exist until now in the market. Different modules provide one or two of the characteristics every time but not in a full package. In addition, the solar application on the plaster was found challenging because of the wanted specific characteristics, which are the lightweight structure and module, with minimum fixings and drillings on the heritage wall and to act as one with the surface without being noticed. Some interventions, which are still in the laboratories, such as printed photovoltaics or the hybrid cement and thin-film modules, could be very promising solutions for façade application. However, these innovations are still under further research and the color possibilities do not match the heritage context, yet.

However, there are some possible suggestions for further research which are based upon the formulation of guidelines and general sustainable building improvements:

- Renovation of the building based on the Greece's Energy Performance Regulations (KENAK) in the climatic zone of Florina.
- Reformulation of guidelines and tools for solar application intervetions.
- Research upon further energy reductions in the building's envelope.
- Research upon forming a micro-energy grid among heritage buildings in the cultural city center, and, furthermore, forming a larger grid combining all buildings in the city's center.

Reflection

Scientific reflection

<u>The relationship between research and design</u>

This thesis is a design by research project. First of all, literature research upon photovoltaic technology and heritage buildings had to be explored in order to form a context of relevant information. Then, the combination of the two different previous subjects formed a new one which was based on literature research and reference case studies, since the subject is still underdeveloped. All these framed the criteria in which the evaluation of a photovoltaic application could be based on. Finally, the criteria structured the characteristics which the design should comply on and thus the different combinations was patterned in the matrix. The final proposal was an outcome of the matrix combinations and calculations regarding energy performance of photovoltaic modules. However, the proposed scenario was also a result of the building's own requirements, since the solar intervention should be relevant and harmonious with the building's urban environment.

<u>The relationship between the graduation topic, master track, and master program</u>

All in all, my graduation topic is a combination of many elements of my master track itself, Building Technology track. The two main factors are the Sustainable Design and the Façade Design, from my track, and Heritage Preservation, from Heritage department. The latter was vital to be explored since it was not a part of my track but was relevant with my thesis project. The needed information had to be collected in order to frame the guidelines in which this special building category has to obey at. Generally my master program is a combination of different sectors of the built environment, from the building construction to building renovation and preservation, but the common factor between all of them is sustainability. This is the element that changes the way of future thinking upon urban environment, and the one that could bring change for the future generations.

<u>Research method and approach chosen in relation to the graduation studio methodical line of inquiry, reflecting thereby upon the scientific relevance of the work.</u>

The methodology chosen for this research was based upon the methodical line of inquiry of the graduation studio. The chosen method for the purpose of this thesis is scientific-technical study and design research by using 2D and 3D computer software. The methodology aims to find ways for design flexibility and adaptability, but at the same time, implying to heritage buildings special requirements. The process was succeeded through computer models and drawings for replicate conditions as close to reality as possible. Therefore, the methodology used literature and design research to improve the aspects of the project and evaluate the results.

<u>The relationship between the graduation project and the wider social, professional and scientific framework, touching upon the transferability of the project results</u>

The impact of the project to the wider society is the possible ways for solar interventions on heritage cases, and especially the design behind the concept. The sustainable interventions for energy production on heritage cases is an important value that leads the design.

The design adaptability of the solar application is part of the zero energy buildings concept that has been promoted globally the last years. Therefore, the export of a methodical tool for solar application in heritage buildings has resulted in an efficient and adaptable design concept. The study concludes in efficient ways to deal with the solar intervention on heritage buildings as it proposes design variations and solutions to deal with the drawbacks of the project.

Since the case study chosen for testing the criteria of solar application on heritage buildings, is a neoclassical structure, the design concept could be applied by the same rules in a different manner in similar style cases in Europe and specially in Greece, since this style is spread in quite every heritage city center. However, that does not mean that in any other heritage case, this concept cannot be used, because the methodology behind the concept is going to follow the same path until the point when the process reaches the building's special requirements. As it have been seen from reference cases, the end result is different and depending on the design requirements of the style and the guidelines from special authorities, but the process of the decision making remains the same. The same study, thus, besides the design variation proposes essential elements that would be the key to apply solar modules in any existed building typology and style.

Additionally, the study achieves to improve and advance the façade design of solar application in an existing building, historic or not, thus contributing to the existing knowledge about the process and offers a tool to the design team to continue with the research in different plot cases.

<u>The ethical issues and dilemmas that may have encountered in doing the research, elaborating the design and potential applications of the results in practice</u>.

The ethical dilemmas behind the research was the same with all references found, that if it is worth investing on solar interventions on heritage buildings since, they are only a small portion of the built stock. In addition to that, the public acceptance and the allowance for the intervention from qualified authorities are big issues to the final result. That is because heritage cases have formed an urban environment that framed the identity of each city center and country, and it cannot be changed easily. But, by first renovation that building portion, to active better building performance, and by second, adding intervention elements for energy production, have many advantages for the building itself, the occupants and the overall urban environment. Specifically, the assessment value of the building rises since is remade viable and safe for the user to live inside and the whole process preserves the building for further deterioration. Furthermore, the overall heritage urban environment keeps its formal glory vivid for future generations which is a living proof of history itself.

Personal reflection

The topic of my graduation thesis first started as a response to the question how photovoltaic technology could be applied on heritage buildings, without compromising their architectural character. It is quite challenging for Architects to and Engineers to design photovoltaic modules which respond to heritage cases, since every style has its own character. My aim with this research is to provide all the tools for applying photovoltaic modules in heritage buildings. From the regulations and guidelines that have to be obeyed , to the different options and combinations depending each case and the end result. Most importantly, with this research, I aim to provide a tool and methodology which begins with a huge variety of options and restrictions, and leads the way to the decision making and the final proposal.

This research focuses on Climate Design and Façade Design, but with a high degree of specific heritage guidelines and aesthetics. In terms of Climate Design, the focus lays on sustainability since the aim of the proposed façade is to promote energy production in heritage buildings and lean the balance to an overall energy transition. The Façade Design was developed in combination with the Climate Design and was derived from energy performance results and heritage guidelines.

As any other research project, I started my study by undergoing some literature research which helped me define the research question and objectives. After the literature research, I was able to filter out the most influential façade design parameters which served as variables in the matrix process. Based on that, the different solutions were formed.

Heritage buildings involve a substantial amount of detail when it comes to interventions and changing the image of them. Each building has a different importance in a local environment and has to be treated differently quite each time. However, as it came out from the research upon reference case studies, there are some criteria that all cases should obey. The important is how well the new intervention is going to interact with the heritage case, the old with the new one. Together with the varies of products, which exist in the market, and those which are still in development, complicate the workflow and it's giving the chance to produce multiple scenarios and combinations.

One of the goals of this study was to evaluate the building's performance under conditions, which are close to reality as possible. Analyzing the solar radiation of the building and, based on the application possibilities that already exist, a first concept is forming on the possible positions that the modules could have on the building. After that, the matrix was formed. All the different criteria and parameters that had to be followed and the specific requirements of my case study, complicated the end result, since there are multiple outcomes with different energy performances. That said, two different energy scenarios were chosen, with two expressions each, one conservative and one progressive. From these scenarios, the most extreme cases were calculated as it comes to energy production and the balancing between the energy demand in each scenario.

The produced intervention was chosen because it is a combination of the scenarios mentioned above. The end result produces around 25 percent of the total energy demand while preserving the image of the heritage building as part of the local urban environment. The energy demand was based to the renovation assumption which is implied from the European Union's regulations and target for each country.

As an overall conclusion about the future interventions in heritage buildings, it is still questionable whether it is worthwhile to invest in these cases and even transform them into near-zero-energy buildings, which is the European Union's aim. However, the more research and development, the more solutions are going be produced and be more efficient and more suitable in every case. Even at this time, there are still many to be improved in terms of technology, but the key to each case is the customization of the products, which make them unique for each end-result.

All in all, new guidelines and regulations for heritage cases should be formed because of the energy transition target, if we want to include them inside the functioning grid. But first and foremost, in order to protect these building from deterioration, is to make them part of every-day life by renovate them and thus needing less energy that once used.

13. Terminology

Building , Listed - Heritage building	-	A building of great historical or artistic value that has official protection to prevent it from being changed or destroyed. (https://dictionary.cambridge.org)
Monument	-	A structure or building that is built to honor a special person or event (UK) (https://dictionary.cambridge.org)
	-	An object, esp. large and made of stone, built to remember and show respect for a person or group of people, or a special place made for this purpose (US) (https://dictionary.cambridge.org)
	-	Architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are outstanding universal value from the point of view of history, art and science (WHC) (https://whc.unesco.org)
Monument, Historic monument	-	An old building or place that is an important part of a country's history. (https://dictionary.cambridge.org)
Conservation	-	The protection of plants and animals, natural areas, and interesting and important structures and buildings, especially from the damaging effects of human activity. (https://dictionary.cambridge.org)
	-	Carefully using valuable natural substances that exist in limited amounts in order to make certain that they will be available for as long a time as possible. (https://dictionary.cambridge.org)
Maintenance	-	The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function. (David Watt, 2011)
Intervention	-	Any action which has a physical effect on the fabric of a building or artefact. (David Watt, 2011)
Preservation	-	The act of keeping something the same or of preventing it from being damaged. (https://dictionary.cambridge.org)
	-	A method involving the retention of the building or monument in a sound static condition, without any material addition thereto or subtraction therefrom, so that it can be handed down to futurity with all the

		evidences of its character and age unimpaired. (David Watt, 2011)
Rebuilding	-	Remaking, on the basis of a recorded or reconstructed design, a building or part of a building or artefact which has been irretrievably damaged or destroyed. (David Watt, 2011)
Reconstruction	-	Re-establishment of what occurred or what existed in the past, on the basis of documentary or physical evidence. (David Watt, 2011)
	-	Returning a place to a known earlier state and distinguished from restoration by the introduction of new material into the fabric. (David Watt, 2011)
Refurbishment	-	Overhauling a building and bringing it up to the requirements of a client. (David Watt, 2011)
Renovation	-	The act or process of repairing and improving something, especially a building, so that it is in good condition again, or the improvements that are carried out. (https://dictionary.cambridge.org)
Repair	-	Work beyond the scope of regular maintenance to remedy defects, significant decay or damage caused deliberately or by accident, neglect, normal weathering or wear and tear, the object of which is to return the building or artefact to good order, without alteration or restoration. (David Watt, 2011)
Restoration	-	The act or process of returning something to its earlier good condition or position (UK) (https://dictionary.cambridge.org)
	-	The act or the process of returning something to its original condition, or to a state similar to its original condition (US) (https://dictionary.cambridge.org)
	-	The aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents. It must stop at the point where conjecture begins, and must be preceded and followed by an archaeological and historical study of the monument. (David Watt, 2011)
Retrofit	-	An occasion when a machine or place is provided with equipment, that it did not originally have when it was built. (https://dictionary.cambridge.org)

14. Bibliography

As resources of this research, any mean is going to be used as literature. Relevant books and technological articles, historical archives and drawings, photographs and personal surveying are going to be the instruments to complete the undertaking.

Annual Reports

Zanetti I. ,Bonomo P. ,Frontini F., Saretta E.(2017) Building Integrated Photovoltaics: Product overview for solar building skins, SUPSI – Swiss BIPV Competence Centre, Status Report,Lugano, Switzerland

Product Booklet

- ERTEX Solar, Product Booklet, Austria,2017
- KS Flex : https://kameleonsolar.com/flexible-solar-panels/
- Kameleon Solar : https://kameleonsolar.com/lof-colored-cells/
- LOF Solar: http://www.lofsolar.com/BIPV-Module

Online Publications

- ICOMOS (Conseil International des Monuments et des Sites), (1999) CHARTER ON THE BUILT VERNACULAR HERITAGE , Ratified by the ICOMOS 12th General Assembly , Mexico.
- Augoustianaki Mich. K., Legislative framework for the protection of cultural heritage, Legal Inspection: Research group of law students in Greece, Greece
- Dong Zhanga, Wim Soppea, Ruud. E. I. Schroppa (2015) , Design of 4-terminal solar modules combining thin-film wide bandgap top cells and c-Si bottom cells, 5th International Conference on Silicon Photovoltaics, SiliconPV 2015,Eindhoven, The Netherlands
- Guzman, P. C. (2017). World heritage cities and sustainable urban development: bridging global and local levels in monitoring the sustainable urban development of world heritage cities Eindhoven: Technische Universiteit Eindhoven.
- Murgul V., (2014) Solar energy systems in the reconstruction of heritage historical buildings of the northern towns (for example Saint-Petersburg), Saint-Petersburg State Polytechnical University, Saint-Petersburg, Russia
- PoloLópez Cr. S., Frontini F.,(2014) Energy Efficiency and Renewable Solar Energy Integration in Heritage Historic Buildings, SUPSI, University of Applied Sciences and Arts of Southern Switzerland, Trevano CP 105, Canobbio CH-6952, Switzerland
- Reinders A.,Diehl J. C., Brezet H. (2013),The Power of Design: Product Innovation in Sustainable Energy Technologies, Chapter: Restyling Photovoltaic Modules,Thung M.,The Netherlands. First Edition, ,John Wiley & Sons, Ltd.
- Tagliabue L. Ch., Leonforte Fa., Compostella J., (2012) Renovation of an UNESCO heritage settlement in southern Italy: ASHP and BIPV for a “Spread Hotel” project, Department of Building Environment Science & Technology, Politecnico di Milano, Via Bonardi 9, Milano 20133, Italy .
- Tzikas, Chris; Valckenborg, R.M.E.; Dörenkämper, Maarten; van den Donker, M.N.; Duque Lozano, D.; Bognár, Á.; Loonen, R.C.G.M.; Hensen, J.L.M.; Folkerts, Wiep, (2018) Outdoor characterization of colored and textured prototype PV facade elements,Published in: Proceedings of the 35th European Photovoltaic Solar Energy Conference and Exhibition
- Veldpaus, L. (2015). Historic urban landscapes : framing the integration of urban and heritage planning in multilevel governance Eindhoven: Technische Universiteit Eindhoven
- Agentschap Onroerend Erfgoed. (2018). Afwegingskader Zonne-energie in een erfgoedcontext. Brussel. Retrieved from www.onroerenderfgoed.be
- Aguacil, S., Lufkin, S., & Rey, E. (2016). Architectural design scenarios with building-integrated photovoltaic solutions in renovation processes: Case study in Neuchâtel (Switzerland). Retrieved from https://upcommons.upc.edu/bitstream/handle/2117/89821/1056-Aguacil.pdf?sequence=1&isAllowed=y
- Amsterdam declaration. (1975). Strasbourg: Directorate of Press and Information. Retrieved from https://www.worldcat.org/title/amsterdam-declaration/oclc/5227174
- Azam, M., Khan, A. Q., Zafeiriou, E., & Arabatzis, G. (2016). Socio-economic determinants of energy consumption: An empirical survey for Greece. Renewable and Sustainable Energy Reviews, 57, 1556–1567. https://doi.org/10.1016/J.RSER.2015.12.082
- Birēs, M. G., & Kardamitsē-Adamē, M. (2004). Neoclassical architecture in Greece. J. Paul Getty Museum. Retrieved from https://books.google.nl/books?hl=el&lr=&id=2eY2DSay5KkC&oi=fnd&pg=PA17&dq=neoclassical+architecture&ots=ZGqNVKB_j-&sig=iswxJ9-pJ1_KO5W70cL3Ez9mXBo&redir_esc=y#v=onepage&q=neoclassical architecture&f=false
- Broström, T., & Svahnström, K. (n.d.). Solar energy and cultural-heritage values. Retrieved from http://www.diva-portal.org/smash/get/diva2:461583/FULLTEXT01.pdf
- Buyle, E. (2018). Afwegingskader zonne-energie in een erfgoedcontext. Afwegingskaders Agentschap Onroerend Erfgoed, 5. Retrieved from http://oar.onroer-

enderfgoed.be/publicaties/AKOE/5/AKOE005-001.pdf

- David Watt. (2011). Surveying Historic Buildings (2nd ed.). Routledge. Retrieved from https://books.google.nl/books?id=QQEwCgAAQBAJ&printsec=frontcover&dq=surveying+historic+buildings&hl=el&sa=X&ved=0ahUKEwi5_-HZpuzkAhVEbFAKHVNjBhcQ6AEIKTAA#v=onepage&q&f=true

- Energy roadmap 2050, E. C. (2011). Energy roadmap 2050. https://doi.org/10.2833/10759

- European Charter for Solar Energy in Architecture and Urban Planning Preamble. (1996). Retrieved from http://www.hermannscheer.de/en/images/stories/pdf/Herzog_European_Charter_Architecture_mar96.pdf

- Hanna, B. (2015). THE FUTURE FOR HERITAGE PRACTICE Foundations of an oral history project: The writing of the Burra Charter, 27(Historic Environment). Retrieved from https://australia.icomos.org/wp-content/uploads/Foundations-of-an-oral-history-project-The-writing-of-the-Burra-Charter-vol-27-no-2.pdf

- Hermannsdörfer, I., & Rüb, C. (2005). Solar design : photovoltaics for old buildings, urban space, landscapes = Photovoltaik für Altbau, Stadtraum, Landschaft. Berlin : Jovis. Retrieved from https://tudelft.on.worldcat.org/oclc/840393592

- INTERNATIONAL CHARTER FOR THE CONSERVATION AND RESTORATION OF MONUMENTS AND SITES (THE VENICE CHARTER 1964). (n.d.). Retrieved from https://www.icomos.org/charters/venice_e.pdf

- Janssen, M. (2018). The contribution of Local Energy Cooperatives to the Energy Transition in The Netherlands. Retrieved from https://www.hieropgewekt.nl/uploads/inline/printFINAL_MasterThesis_MattieJanssen_s1014612.pdf

- Kaldellis, J. K., Kapsali, M., & Katsanou, E. (2012). Renewable energy applications in Greece—What is the public attitude? Energy Policy, 42, 37–48. https://doi.org/10.1016/j.enpol.2011.11.017

- Kuipers, M., & Jonge, W. de. (2017). Designing from Heritage. BK BOOKS. Retrieved from https://books.bk.tudelft.nl/index.php/press/catalog/book/isbn.9789461868022

- Lutz, P., & Scherrer Institut, P. (2018). CCEM_Final Activity Report_2006-2017. Retrieved from www.ccem.ch

- Manolopoulos, D., Kitsopoulos, K., Kaldellis, J. K., & Bitzenis, A. (2016). The evolution of renewable energy sources in the electricity sector of Greece. International Journal of Hydrogen Energy, 41(29), 12659–12671. https://doi.org/10.1016/j.ijhydene.2016.02.115

- Mondol, J. D., & Koumpetsos, N. (2013). Overview of challenges, prospects, environmental impacts and policies for renewable energy and sustainable development in Greece. Renewable and Sustainable Energy Reviews, 23, 431–442. https://doi.org/10.1016/j.rser.2013.01.041

- Murgul, V. (n.d.-a). Methodology to Improve Energy Efficiency of Residential Historic Buildings in St. Petersburg. https://doi.org/10.1051/C

- Murgul, V. (n.d.-b). Solar energy systems in the reconstruction of heritage historical buildings of the northern towns (for example Saint-Petersburg). Journal of Applied Engineering Science, 12(2), 121–128. https://doi.org/10.5937/JAES12-6136

- Ntona, E., Arabatzis, G., & Kyriakopoulos, G. L. (2015). Energy saving: Views and attitudes of students in secondary education. Renewable and Sustainable Energy Reviews, 46, 1–15. https://doi.org/10.1016/J.RSER.2015.02.033

- Paul Meurs. (2016). Heritage-based design. BK BOOKS. Retrieved from https://books.bk.tudelft.nl/index.php/press/catalog/book/484

- Polo López, C. S., & Frontini, F. (n.d.). Solar Energy Integration-Challenge and Chance for Conservation Architects. Retrieved from https://s3.amazonaws.com/academia.edu.documents/43353364/Challenge_and_Chance_for_Conservation_Ar20160304-25617-vahx0m.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1549830379&Signature=u-97ZHCU6O7fKZmWxh3Bf4s1tcPY%3D&response-content-disposition=inline%3Bfilename%3DChallenge_and_Chance_for_Conservation_Ar.pdf

- Rob van Hees, Silvia Naldini, & Job Roos. (2014). Durable past- sustainable future. BK BOOKS. Retrieved from https://books.bk.tudelft.nl/index.php/press/catalog/book/isbn.9789461863638

- Rob Zakee. (2019). Zonne-Energie en erfgoed Hoe kan erfgoed bijdragen aan de opwekking van zonne-energie? Retrieved from https://www.hieropgewekt.nl/uploads/inline/20190207- Rapport zonne-energie en erfgoed_def.pdf

- Skandalos, N., Tywoniak, J., & Maierova, L. (2019). The PV Potential in the City of Prague : Methodology and Assessment for Residential Buildings, (January).

- Stephanides, P., Chalvatzis, K. J., Li, X., Mantzaris, N., Prodromou, M., Papapostolou, C., & Zafirakis, D. (2019). Public perception of sustainable energy innovation: A case study from Tilos, Greece. Energy Procedia, 159, 249–254. https://doi.org/10.1016/j.egypro.2018.12.058

- Strategic Energy Technology (SET) Plan ANNEX I: Research and innovation actions Part I-Energy Efficiency JRC93058 Acknowledgements to Drafters and Contributors. (n.d.). Retrieved from https://setis.ec.europa.eu/system/files/IR_Annex I_Part I_Energy Efficiency.pdf

- Tagliabue, L. C., Leonforte, F., & Compostella, J. (2012). Renovation of an UNESCO Heritage Settlement in Southern Italy: ASHP and BIPV for a “Spread Hotel” Project. Energy Procedia, 30, 1060–1068. https://doi.org/10.1016/J.EGYPRO.2012.11.119

- Tampakis, S., Arabatzis, G., Tsantopoulos, G., & Rerras, I. (2017). Citizens’ views on electricity use, savings and production from renewable energy sources: A case study from a Greek island. Renewable and Sustainable Energy Reviews, 79, 39–49. https://doi.org/10.1016/j.rser.2017.05.036

- THE NARA DOCUMENT ON AUTHENTICITY (1994) PREAMBLE. (n.d.). Retrieved from https://www.icomos.org/charters/nara-e.pdf

- UNESCO General Conference Paris. (1972). UNITED NATIONS EDUCATIONAL, SCI-

ENTIFIC AND CULTURAL ORGANISATION CONVENTION CONCERNING THE PROTECTION OF THE WORLD CULTURAL AND NATURAL HERITAGE. Retrieved from http://whc.unesco.org/archive/convention-en.pdf

- Walker, G., Devine-Wright, P., Hunter, S., High, H., & Evans, B. (2010). Trust and community: Exploring the meanings, contexts and dynamics of community renewable energy. Energy Policy, 38(6), 2655–2663. https://doi.org/10.1016/J.ENPOL.2009.05.055

- Zografakis, N., Sifaki, E., Pagalou, M., Nikitaki, G., Psarakis, V., & Tsagarakis, K. P. (2010). Assessment of public acceptance and willingness to pay for renewable energy sources in Crete. Renewable and Sustainable Energy Reviews, 14(3), 1088–1095. https://doi.org/10.1016/J.RSER.2009.11.009

- Ζαρκάδα-Πιστιόλη, Χ., & Χριστίνα. (2003). Η αρχιτεκτονική της Φλώρινας στην περίοδο του μεσοπολέμου. Retrieved from https://www.didaktorika.gr/eadd/handle/10442/20520

Historical Archives

- Decision of inserting the building into the listed monuments, (original from 1987) , given by the partially owner Ms. Pinopoulou E.

- Antoniadis G. , Kiatipis E (1980) , For the salvation of the neoclassic building " International", Letter and Drawings.

- The Macedonian Diaries of neoclassic buildings of Florina (1988), Magazine of the local authorities of Florina

Books

- Bamicha A.,(2008) Public and private land in Athens the first decade after the Independence: Case of George Finlay, MSc Thesis in Aristotle University of Thessaloniki, School of Philosophy, Department of History and Archeology, Sector of New and Contemporary History and Folklore.

- Birēs M, Kardamitsē-Adamē M, (2004) Neoclassical architecture in Greece, Publisher: 1st Melissa Publishing House (2001), 2nd J. Paul Getty Museum (2004) , Athens, Greece.

- Bold John, Larkham Peter, Pickard Robert, Authentic Reconstruction: Authenticity, Architecture and the Built Heritage, published by Bloomsbury Academic Plc, London & USA, 2018.

- Desilvey Caitlin, Curated Decay: Heritage beyond saving, University of Minnesota Press, Minneapolis, 2017.

- Hermannsdorfer I., Rub Ch. (2015) Solar Design : Photovoltaics for Old Buildings, Urban Space, Landscapes, jovis Verlag, Berlin.

- Kuipers M. ,Jonge W. (2017), Designing from Heritage –Strategies for Conservation and Conversion,TU Delft.

- v. Hees R., Naldini S.,Roos J. (2014), Durable past – sustainable future, TU Delft.

- Meurs P. (2016), Heritage-based design, TU Delft.

- Mekasis D. (2018), Neighborhoods of the old town of Florina, General Central Library of Florina: Vasiliki Pitoska.

- Zarkada-Pistioli Ch., (2003) , Architecture of Florina in the time of Middlewar, PhD Thesis in Aristotle University of Thessaloniki , Polytechnical School Department of Architecture, Thessaloniki.

Drawings

Original Drawing of the building (from 1924) Given by Papagiannakis M. , Department of town planning of Florina, Scale 1:100

Topographical diagram, by Soulas A., Robis T., Nikolaou S. (2007), Scale 1:200

Witnesses

Poritsa M., member of the Cultural center of "International"

Antoniadis G. , chairman of the Cultural center of "International"

Web Pages

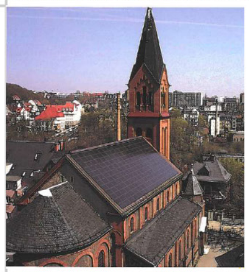
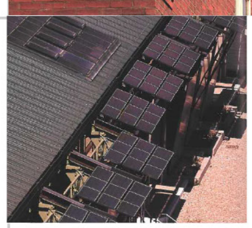
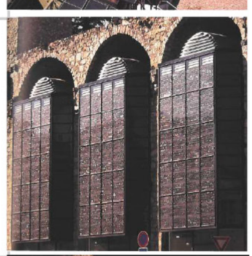
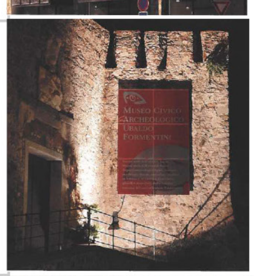
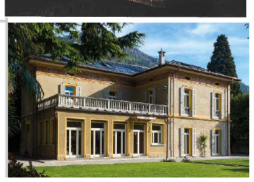
- https://www.icomos.org/en/and/169-the-declaration-of-amsterdam
- Governmental Decree https://nomosphysis.org.gr/15090/ste-15872010-paranomi-egkrisi-yppo-gia-tin-anoikodomisi-adomitoy-oikopedoy-ston-oikismo-tis-ydras/
- http://www.zebra-monitoring.enerdata.eu/
- https://www.getty.edu/conservation/our_projects/field_projects/values/index.html
- https://www.foreground.com.au/culture/forty-years-of-the-burra-charter-and-

australias-heritage-vision/

- http://www.getty.edu/conservation/publications_resources/research_resources/charters/charter55.html
- http://slapcoffee.com/2019/03/20/global-rooftop-solar-photovoltaic-pv-market-2019-top-key-players-jinko-solar-trina-solar-canadian-solar-ja-solar-hanwha/
- http://www.hermannscheer.de/en/images/stories/pdf/Herzog_European_Charter_Architecture_mar96.pdf
- https://www.swissinso.com/rise
- https://www.tesla.com/nl_NL/solarroof
- (http://www.pvaccept.de/pvaccept/eng/produkteober.htm
- http://www.pvaccept.de/eng/portovenere.htm
- https://ecochurchsouthwest.org.uk/
- https://arcuatearchitecture.com.au/sustaining-churches/
- http://www.pvdatabase.org/projects_view_details.php?ID=70
- https://www.sunstyle.com/en/References.html
- http://www.cazzarocostruzioni.it/ita/en
- http://www.jointpublicissues.org.uk/wp-content/uploads/2018/01/solar-panels-guidance-0612.pdf
- https://www.saint-silas.org.uk/
- http://www.bipv.ch/index.php/en/histori-s-en/item/943-romancatholichparish-eng
- http://www.issol.eu/solarterra/
- https://www.sunstyle.com/en/References.html
- https://www.open.edu/openlearn/history-the-arts/history/heritage/ciam-congres-internationaux-darchitecture-moderne
- http://kparlapani.blogspot.com/2010/01/blog-post_3651.html
- https://www.google.com.br/maps/@40.7780841,21.4075867,3a,75y,307.68h,97.67t/data=!3m6!1e1!3m4!1sC6oVAGArtDuJXYzCD9SjhA!2e0!7i13312!8i6656
- http://enplosimioseis.blogspot.com/2016/05/blog-post_12.html
- https://www.zep.solar/nl/producten/nibra_f10u-redline-natuurrood

Appendix

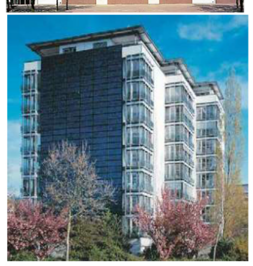
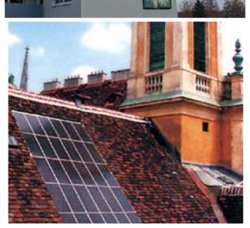
1. Reference Study Cases Table

Name of the building	Retrofit figure	Location	Land of use	Owner	Architect	Energy Consultant
Church in Carlow		Barwalde,Germany	Church	Ev.-luth. Kirchengemeinde	Bezirkskirchenamt Dresden	Ingenieurburo,Dr.Scheffler & Partner GmbH
Church in Osnabrück		Osnabruck,Germany	Church	Land Niedersachsen	Planungsburo Rohling AG	Decker & Mack
Herz-Jesu-KircheinPlauen		Dresden-Lobtau/Germany	Church	Katholische Pfarrei St.Antonius	Schulze + Partner	Ingenieurburo Dr.Scheffler & Partner GmbH
Deutsche Werkstätten (German Workshops)		Dresden-Hellerau, Germany	Buisness	Grundbesitz Hellerau GmbH	Peer Haller, Rudolf Morgenstern, Albrecht Quincke	SunStrom
Gusto Homes		Allington, England	Residential	Steff Wright	Gusto Homes	Solarcentury
Children's Museum		Rome, Italy	Museum	Museo dei Bambini di Roma	Studio Italplan	Gechelin Group, AeV Abbate e Vigevano Architetti
Tourist Information Bureau		Alès, France	Tourist Info	Ville d' Alès	Jean-François Rougè	SOLARTE
Monument castle San Giorgio (Solar Information Board)		La Spezia, Italy	Board	Comune di La Spezia	PVACCEPT / UdK Berlin	PVACCEPT / BUSI IMPIANTI
Villa Castelli		Lago di Como, Italy	Residential	Privately owned	Daniel Herrera	---

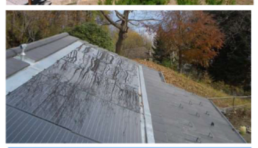
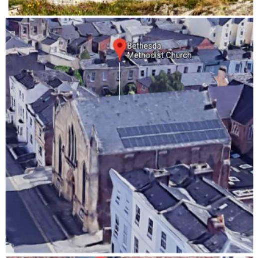
System ProvideR / Installer	Year of Construction	Year of Retrofit	Energy Output {kWp} (peak)	Energy Yield {kWh/a} (per year)	Area {m²}	Number of Pv modules	Type of Pv modules
SachsenSolar AG	1867	2004	2.1 kWp	1.780 kWh/a	40 m2	622	Polycrystalline glass/foil
ThyssenKrupp Solartec	19th century	2003	22.53 kWp	18.000 kWh/a	460 m2	---	Light-weight construction made from galvanised aluminium onto nano-crystalline thin-films are laminated
Solarwatt	1924	2001	3.45 kWp	2.900 kWh/a	26.5 m2	30	Frameless monocrystalline black solar cells with black dyied metal conductors and black backing foil. A finely structured highly transparent cover glass was added.
Solarwatt	1909/10	2003	29.04 kWp	22.500 kWh/a	242 m²	---	Polycrystalline standard solar modules
Solarcentury	---	2003	1 kWp	1 kWp	9.6 m²	---	Modules with appearance and behavior to normal roofing tiles
Eurosolare	1620	2001	15 kWp	188.000 kWh/a	218 m²	---	System of polycrystalline silicon cells
Photowatt	16th century	2001	9.6 kWp	6.000 kWh/a	100 m²	---	The brown solar cells used were especially adapted to match the colour of the limestone material of the church. The modules are semitransparent due to the interspaces between the cells, allowing daylight into the interior of the building.
PVACCEPT / Würth Solar	---	2004	720 Wp	350 kWh/a	8.6 m²	6	A board consisting of six oversized (1.20 m x 1.20 m) thin-film photovoltaic modules. The innovative idea of screen-printing an even matrix of dots onto the modules using weather resistant ceramic colour was developed by PVACCEPT
---	second half of 19th century	---	---	---	---	---	---

Name of the building	Retrofit figure	Location	Land of use	Owner	Architect	Energy Consultant
Rural house Galley		The Ecuvillens, France	Farm house	Privately owned Alexandre Galley	Lutz architects	CSEM SA
La Cigale		Geneve, Switzerland	Residential	Privately owned Board of Directors "La Cigale"	François BAUD & Thomas FRÜH architecture studio	BG Consulting Engineers, Mr Benoit Müller
The Glaserhaus		Affoltern in the Emmental, Belgium	Residential	Privately owned Christian and Elisabeth Anliker	Christian & Elisabeth Anliker	clevergie gmbh, Bern region
Solar Silo		Basel, Switzerland	Residential	Kantensprung AG	Baüburo In situ AG	SOLVATEC AG
Ogg landwirtscraft		Regensdorf-Watt , Switzerland	Farm house	Ogg Philip	---	---
Solar Church		Halden, Canton St. Gall, Switzerland	Church	Evang. Kirchgemeinde Tablat, Kath. Kirchgemeinde St.Galle	Forrer Krebs Ley, St Gallen	Energiebüro AG, Zürich
Werner Farm		Allschwill, Canton Basel, Switzerland	Farm house	Hans Werner	---	TRITEC AG Schweiz
Roman Catholic Parish St Peter and Paul		Ettingen, Canton Basel, Switzerland	Church	Roman Catholic Parish of Ettingen	---	Solvatec AG
Private house in Flums		Flums, Canton St. Gallen , Switzerland	Farm house	Ursi and David Wildhaber Family	---	---
Reinhaltungsverband Hallstaettersee		Austria	Buisness	Reinhaltungsverband Hallstättersee	Wels Strom GmbH	Wels Strom GmbH
MFH Amsterdamer Strasse		Cologne, NRW,Germany	Residential	Antoniter siedlungsgesellschaft	---	Antoniter siedlungsgesellscha ft

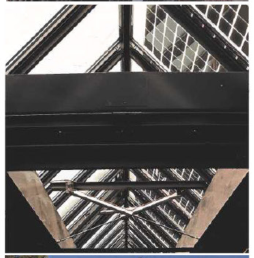
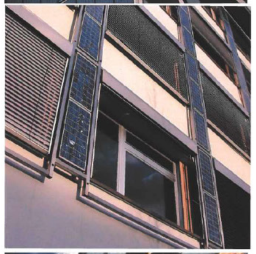
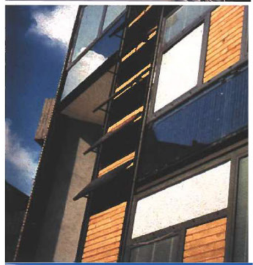
System ProvideR / Installer	Year of Construction	Year of Retrofit	Energy Output {kWp} (peak)	Energy Yield {kWh/a} (per year)	Area {m²}	Number of Pv modules	Type of Pv modules
Issol Suisse Ltd	1859	2017	27.2 kWp	16.500 kWh / a	262 m²	---	The Ecuvillens rural house pilot project uses clay colored modules (tiles) developed specifically by the CSEM of Neuchâtel and Issol Switzerland for sites protected by cultural heritage, with reduced efficiency by about 39% due to colour change in comparison with the traditional panels. (persentage supposition for non-insulated buildings) The installation produces 26% energy of the total energy demand)
Signa-Terre SA, Mr. Jan Schneider	1952	2013		554.800 kWh/a (52% of annual requirements)	1.670 m²	---	solar thermal panels
---	1765	2015	89.4 kWp	74.000 kWh /a	550 m²	485,5	the 89 kW PV system. The high quality of the BEP renovation ensures a self-production of 345%, with a consumption of 26,200 kWh / according to the Minergie-P label.
Antec Solar SwissInso Kromatix	2015	2015	23 Wp	16.400 kWh /a	159 m²	---	Solar Silo is an example where the integration of coloured PV modules in the opaque parts of roof and facade building envelope is experimented. The colour is obtained thanks to the patented technology Swiss Inso Kromatix. Custom-size coloured crystalline photovoltaic modules are used on facades (monocrystalline cells, glass/glass, frameles. Standard-size coloured crystalline PV modules on the roof (monocrystalline cells, glass/backsheet
WIndGate AG	1979	2013	271.32 Wp	220.329 kWh /a	1.740 m²	1064	Multicrystalline , Dark Blue Opaque, Frameless
Ars solaris Hächler	1986	2010	46 Wp	49.000 kWh /a	255 m²	---	Monocrystalline Indach SunPower Solrif, Blue opaque
TRITEC AG Schweiz	2011	2011	110.08 Wp	140.576 kWh /a	---	512	KYOCERA KD215GH-2PU ,multicrystalline (156x156mm), Black, opaque with black anodized frame, The PV plant was installed on the sloped roof through the TRI-ROOF mounting system, in which the modules replace the final roofing layer .
Solvatec AG, JaSolar Jam6(BK)	1914	2013	60 Wp	57000 kWh /a	382 m²	233	The intervention on the original building was aimed to create a full PV roof without modify the global image and perception of the church within the landscape. Monocrystalline modules, replacing the old rood tiling, Black, opaque ansd farmeles
---	1700	2010	9,5 Wp	10.000 kWh /a	---	---	The new roof is a replacement of an existing granary roof, consisting in a complex integration with 10-12 cm interspace for providing the ventilation and cooling of PV cells. Black Opaque
SCHOTT Solar GmbH	---	2005	17.6 kWp	19.590 kWh /a	---	84 (0.21 kWp)	Framed - regular module,Crystalline silicon - multi
Sharp	---	2005	27 kWp	25000 kWh /a	---	---	Crystalline silicon - multi, Framed - regular module

Name of the building	Retrofit figure	Location	Land of use	Owner	Architect	Energy Consultant
ENSAM Lille		Lille, France	Educational	ENSAM Lille	---	ENSAM Lille
Apex Bp Solar		Austria	Tourist Info	Austrian Tourist Club (ÖTK)	Marie Rezac -Pos architekten	Austrian Tourist Club (ÖTK)
Maziere nature reserve		Villeton, France	Farm house	SEPANLOG	---	SEPANLOG
Council technical building		Agen, France	Buisness	Ville d'Agen	---	Apex Bp Solar
3 kW PV rooftop with 'Swiss' PV rooftiles		Lekkerkerk, Zuid-Holland, Netherlands	Residential	---	---	ENECO Energy Systems & Services
Sun screen Leeuwenhorst Congres Centrum		Noordwijkerhout, Zuid-Holland, Netherlands	Public use	Golden Tulip Conference Hotel Leeuwenhorst	C. Zorge	Shell Solar Energ
Wilmersdorfer Straße		Freiburg, Baden-Württemberg, Germany	Residential	Familienheim Freiburg, Baugenossenschaft e.G.	rolf + hotz architekten, Freiburg	---
Islay Columba Centre		Bowmore, Isle of Islay, United Kingdom	Public use	---	Gillespies	---
Experimental use of Evalon Solar in Single Family House		Cerceda, Madrid, Spain	Residential	Intemper	---	Alwitra-Unisolar
Solar Energy Housing Estate Köln-Bocklemünd (II)		Cologne, North Rhine-Westphalia, Germany	Residential	Antoniter Siedlungsgesellschaft mbH (ASG)	---	Ecofys Germany GmbH
PV Church Vienna		Vienna, Austria	Church	Reformierte Kirche	---	Reformierte Kirche

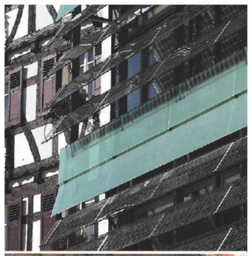
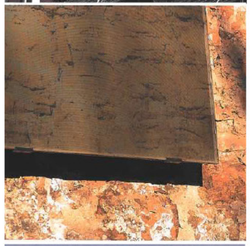
System ProvideR / Installer	Year of Construction	Year of Retrofit	Energy Output {kWp} (peak)	Energy Yield {kWh/a} (per year)	Area {m²}	Number of Pv modules	Type of Pv modules
Apex Bp Solar	---	2004	17 kWp	---	---	108	Laminates - regular laminate, Crystalline silicon - multi
---	---	2005	7.5 kWp	8222 kWh /a	---	---	Laminates - transparent laminate, Crystalline silicon - multi
Tenesol	---	2005	13.6 kWp	14000 kWh /a	---	---	Framed - regular module, Crystalline silicon - multi
Apex Bp Solar	---	2005	15 kWp	16.500 kWh /a	150 m²	---	Framed - regular module, Crystalline silicon
R&S (Shell Solar Energy; PV cells), SMA (inverters)	---	1993	2.85 kWp	2.000 kWh /a	33,5 m²	90	Laminates - regular laminate, Crystalline silicon - multi
Golden Tulip Conference Hotel Leeuwenhorst	---	1998	18 kWp	13.000 kWh /a	180 m²	---	Grid-connected - demand side, Laminates - regular laminate
---	1998	2001	51 kWp	29.195 kWh/a	2x230 m²	---	Framed - regular module, Crystalline silicon - mono
SES Atlantis	1902	2003	19.73 kWp	8.164 kWh/a	197 m²	---	PV building elements - PV roof tile,Crystalline silicon - multi
Evalon Solar (Alwitra-Unisolar)	---	2005	2.856 kWp	---	---	---	PV building elements, Amorphous silicon
---	---	2002	9.3 kWp	---	---	---	Framed - regular module
Elektric Installations: Elektro Korkisch	1794	1997	3.3 kWp	---	---	---	Framed - regular module, Crystalline silicon - mono

Name of the building	Retrofit figure	Location	Land of use	Owner	Architect	Energy Consultant
Elementary School Thüringerberg		Thüringerberg, Vorarlberg,Austria	Educational	Community Thüringerberg	---	SOLAR-FABRIK AG
Blackpool Solaris Centre		Blackpool, Lancashire,United Kingdom	Educational	Blackpool Council	---	---
Alpine chalet Kuhn		Brissago, Canton Ticino, Switzerland	Residential	Privately Owned, Fam. Kuhn, Brissago	---	TRITEC AG Schweiz, Zweigniederlassung
St. Silas Church		Penton Street , London, England	Church	Community Pentoville	S S Teulon	Wayne Mills
Farmhouse in Bruttelen		Bruttelen, Belgium	Farm house	Privately Owned	---	SUNSTYLE
Church in the Strand Municipality		Strand, Norway	Church	Community in Strand	---	SUNSTYLE
Hotel Grimsel Passhole		Switzerland	Hotel	Privately Owned	---	SUNSTYLE
Bethesda Methodist Church		Gloucestershire, England	Church	---	---	---
Casa S. Orsola		Treviso, Italy	Hotel	CazzaroCostruzioniS.r.l .	Imago Design - Domenico Rocco	---
Stalder in Ortsbild-Schutzonne		Neustadtstrasse , Luzern, Switzerland	Residential	Alois Stalder	Stanislav Stancik	BE | Netz AG

System ProvideR / Installer	Year of Construction	Year of Retrofit	Energy Output {kWp} (peak)	Energy Yield {kWh/a} (per year)	Area {m²}	Number of Pv modules	Type of Pv modules
SOLAR-FABRIK AG	---	2003	17.95 kWp	20098 kWh/a	---	---	Framed - regular module, Crystalline silicon-multi
Saint Gobain	1938	2003	18.067 kWp	12.776 kWh /a	164.2 m²	178	Crystalline silicon - multi, Laminates - transparent laminate
TRITEC AG Schweiz, Zweigniederlassung	---	2009	1.78 kWp	2,130 kWh/a	---	12	The PV tiling replaces the function of the roof tiling with the watertightness role. Black, opaque, frameless. MegaSlate in high efficiency monocrystalline cells with the power.
Nu-Lok	1863	2003	14.84 kWp	12,337 kWh/a	---	362	The first of heritage buildings in UK that embraces the pv. The panels used were specially designed to match the colour of the slate following discussions with the architect and planning authority
SUNSTYLE	18th century	---	35 kWp	---	265 m²	---	The flexible application of the solar roof makes it possible to completely cover the trapezoid-shaped roof homogeneously.
SUNSTYLE	19th century	---	25 kWp	20,000 kWh/a	---	---	---
SUNSTYLE	1956	---	35 kWp	35,000 kWh/a	260 m²	---	---
---	1867	2009	---	7.000 kWh /a	---	32	They are not visible from the main road at the front of the building
Systems-Vincenzo Conte Structures -Giovanni Crozzolin	1300	2007	3.3 kWp	3.680 kWh /a	15,92 m²	---	---
BE | Netz AG	1970s	2015	34.4 kWp	23,100 kWh / a	200 m²	22 special and 36 blind modules	Special modules form a uniform and harmonious roof surface with the filigree roof windows. The sophisticated architecture meets the high standards of heritage protection and enhances the cityscape.

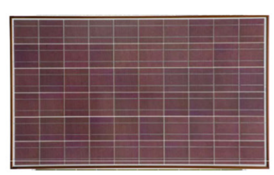
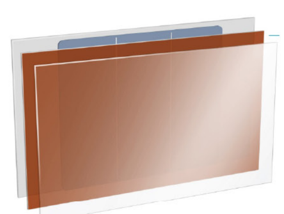
Name of the building	Retrofit figure	Location	Land of use	Owner	Architect	Energy Consultant
The Uitikon Action Center		Uitikon, Zurich, Switcherland	Farm house	Office for Correction Canton Zurich	---	Savenergy Consulting GmbH
Dormer		Bremen, Germany	Residential	Privatelly owned	---	BUND
Academy Building		Meissen, Germany	Educational	Evangelic Academy Meissen	Architecturburo Pfau	Ingenierburo Dr. Dcheffler & Partner GmbH
Performing Arts Facility "Arena"		Berlin, Germany	Public use	Art Kombinat e.V. Kultura'era GrrbH	dernel arch irekten	EnergieSystemTech ni
Lárche" House		Bunwald , Switzerland	Residential	Markus & Margreth Hermann	Markus Hermann	Amena
Multi-Storey Building		Delft, Netherlands	Residential	Woonbron Delft	Van Schagen architekten	W/E adviseurs
Administrative Office of the Building Surveyor's Office		Feldkirch, Austria	Buisness	Land vorarioerg	Landeshochbajarnt Feidkrch	Landeshochbauam t Feidkirch
Apartment Building		Aalborg, Denmark	Residential	Municipality of Aalborg	Jacob Blegvad	Eabenaen Conaulting Engineera
Karren Cable Car		Dornbirn, Ausrtia	Educational	Municipality of Dornbirn	Leopold Kaufmann	stromaufwarts

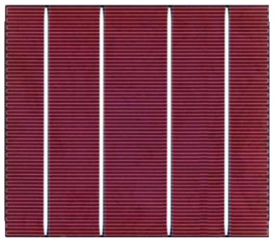
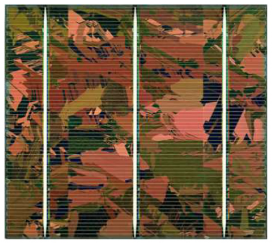
System ProvideR / Installer	Year of Construction	Year of Retrofit	Energy Output {kWp} (peak)	Energy Yield {kWh/a} (per year)	Area {m²}	Number of Pv modules	Type of Pv modules
Alex Gemperle AG	---	2015	224 kWp	205,100 kWh /a	1.500 m²	---	monocrystalline solar cells
Osmer solar	1950s	2003	4.3 kWp	3.250 kWh / a	34.9 m²	27	Multicrystalline photovoltaic, replacing roof tiles
SOLARWATT	13th century	2002	2.76 kWp	2.300 kWh / a	21 m²	24	Black monocrystalline cells. They are used both as roof and shading
Saint Gobain Glass	1928	1999	30 kWp	620 KWh/a	209 m²	---	Monocrystalline standard cells intergrated into the glazing of the skylights of the roof
BP solar	1965	2000	1.6 kWp	1.500 kWh /a	15 m²	8	Semitransparent PV system, double glass with grey monocrystaline cells. They used as canopy to the balcony.
BST Group	1965	2003	26.4 kWp	17.800 kWh / a	260 m²	138	100 standard modules with 55 polycrystalline solar cells each on the south façade, 38 standard modules with 60 polycrystalline cells each above the access gallery of the top storey, flexible thin-film solar cells on synthetic waterproof material on 114 m2 of the roof of the attached flat building; and two oversized mod ules with twice 84 semitransparent monocrystalline solar cells on each of the balustrades of two balconies.
stromaufwarts	1960s	1998	5.35 kWp	3.000 kWh/a	45 m²	---	Blue polycrystalline in accordance with the dimentions of the building, integrated ino stainless steel sun shade construction and emphasise the vertical lines of the building.
GAIA Solar	1900	1996	2.8 kWp	700 kwh/a	22 m²	---	Rear ventilated moduels. In angle on the roof and vertically on the façade.
stromaufwarts	1950s	1996	2.65 kWp	700 kWh/a	21 m²	32	Crystalline moduels were mounted below the windows in front of the renovated south faacde.

Name of the building	Retrofit figure	Location	Land of use	Owner	Architect	Energy Consultant
Public Utilities Administrative Building		Aachen, Germany	Public use	STAWAG StadiwerKe	Georg Feinhals	STAWAG StadiwerKe
Kollektivhuset		Copenhagen, Denmark	Residential	Vanfares Boigselskab & Kobenbavns Kommjne	Domus Arkitekter	Esbensen consusing Engineers
Energy Research Centre		Pettn , Netherlands	Buisness	Netherlands Energy Research Foundation	BEAR Architecten	EON & Shell Solar
Editing Office		Albstradt, Germany	Buisness	Zollern-Alb-Kurier	Friedrich Rau, Axel Schlueter	Delzer Kybernetik
Solar Quotation Board at City Wall		Marbach , Neckar, Germany	Board	Stadt Marbach am Neckar	PVACCEPT / UdK Berlin	PVACCEPT / worth Solar
"Sun Trap" ("Sonnenfalle") at College of Fine Arts		Hamburg, Germany	Board	Hochschule fr bildende Künste	Handle, Niemeyer, Riepe	solarnova

System ProvideR / Installer	Year of Construction	Year of Retrofit	Energy Output {kWp} (peak)	Energy Yield {kWh/a} (per year)	Area {m²}	Number of Pv modules	Type of Pv modules
FLABEG Solar International	1960s	1991	4.2 kWp	290 kWh/a	37 m²	103	Pioneer to the use of modules with solar cells embeded within insulation glass. A special foil was placed between the inner panes to diffuse incident light. There were custom-made to correspond with the existing segmentation of the façade. The cabling is completely integrated into the metal frames of the facade.
Gaia Solar	1950s	2002	12 kWp	500 kWh/a	166 m²	---	The PV system was integrated into the new glass façade at the alustade level. Different colored glasspanesbehind the solar modules create a picture of varying use of the balconies.
Shell Solar	1963	2001	26.21 kWp	20 000 kWh/a	262 m²	---	Solar modules as sun protector.
PHP Glastec-Systeme	1970s	2004	4.3 kWp	4.500 kWh/a	84 m²	---	The sutters slats adjust themselves automatically, depending on the position of the sun. They consist of semitransparent crystalline.
PVACCEPT / worth Solar	---	2004	1.080 Wp	600 kwh/a	13 m²	9	To ensure optical harmony with the natural stone of the historical city wall, the structure and colours of the wall were adopted as background design for the modules. The basic pattern of all nine modules is identical.
solarnova	---	1998	2 kWp	1.600 kWh /a	21.3 m²	---	Attractive landmark. Multicrystalline solar cells which were set apart at larger dinstances than actually required for technocal reasons and embeded in glass.

2. Options for Photovoltaic Application on Roof of Heritage Cases

Roof					Type	Maximum power per roof tile	Power tolerance	Quantity per m²	Price indicator
	Tiles								
		Teracotta-like	Solarteg tiles						
			Tesla Solar Tiles						
			SUNSTYLE Tiles		Monocrystalline	162 Wp/ m2			
			ZEP Solar , Nibra F10U Redline Natural red, https://www.zep.solar/nl/producten/nibra_f10u-redline-natuurrood			8W	0,30%	9.8 pieces	€ 256 excl. VAT per m2
		Grey-Blue	Hantile Roof Tile		Thin Film	105 Wp/ m2			
			Tesla Solar Tiles						
	Panels								
		Terracotta-like							
			LOF Coloed cell- Marble Tile Red Color, http://www.lofsolar.com/Standard-PV-Module#5		Multi-crystalline Silicon	260 Wp per module			
			Solar Terra, ISSOL, http://www.issol.eu/solarterra/		Monocrystalline	106 - 120 Wp/ m2			

		Type	Maximum power per roof tile	Power tolerance	Quantity per m²	Price indicator	Extra Details
Kameleon Print		Monocrystalline	80 - 150 Wp /m2				4mm tempered solar glass , Ceramic ink, hardened on the outside of the glass
Eleven Solar, M36-10 Terracotta, Module & Tile, http://www.elevensolar.com/m36-10-terracotta/		Monocrystalline	36 Wp per module				
Kameleon Coloed cell- One Color		Multi-crystalline Silicon	4.37 - 4.03 W per cell				
Kameleon Coloed cell- Marble Metallic Gold Color		Polycrystalline	80 - 150 Wp per m 2				4 to 6 mm tempered solar glass, structured or flat, low iron content, Alkaline texture with SINx anti-reflective coating
Kameleon Kromatix		Monocrystalline	80 - 150 Wp per m 2				3.2mm or 4mm tempered solar glass, A multi-layered coating on the inside of the glass, applied by a process with low-pressure plasma. No pigments or dyes are used. The outside of the glass is treated so that there is a diffuse reflection and no glare occurs.

3. Questionnaire

Installation of photovoltaic panels in a cultural building.

1) Age

- o Up to 20 years old
- o 20 – 30 years old
- o 30 – 40 years old
- o 40 – 60 years old
- o 60 years old and older

2) Educational Level

- o Primary education
- o Secondary education
- o Tertiary education

3) Do you recognize this building?

- o Yes
- o No

4) Do you think that this building should be renovated?

- o Yes, because it has a vital significance for the city's identity.
- o No, because it could be replaced with a newly constructed structure.

5) Did you know if the building had a different color when it was firstly constructed?

- o Yes
- o No

6) From testimonies, we know that the building called “Diethnes” ("International") had another color rendition in the early years of its operation. The original and the present form are presented below. In which of the two forms would you prefer to renovate this building?

- o First choice
- o Second choice
- o None of the above

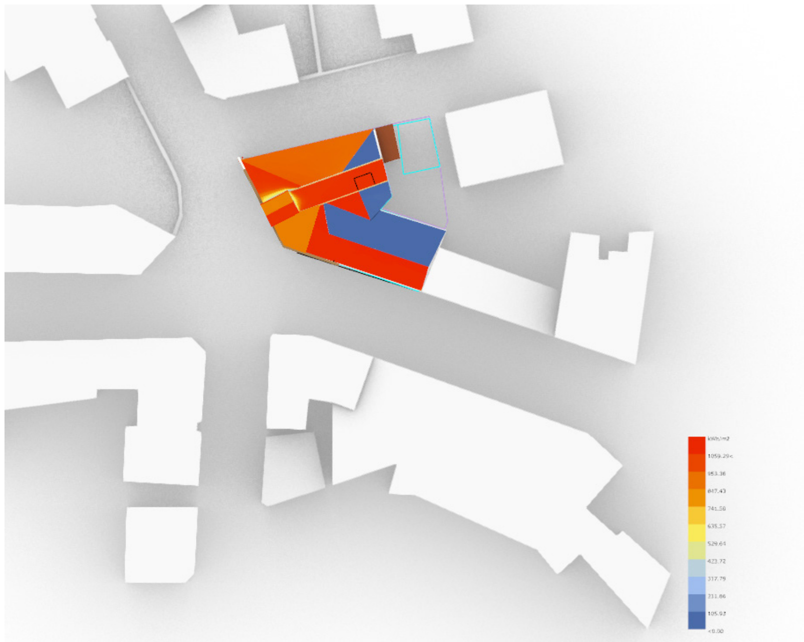
7) Do you know about electricity and hot water production by installing photovoltaic panels in buildings?

- o Yes
- o No

8) The image below shows the placement of photovoltaic panels in a random building. What is your opinion on the image of the building?

- o I am annoyed by the existence of the panels, because they do not "fit" with the building.
- o I don't mind the existence of the panels, because they "fit" with the building.
- o I don't mind the existence of the panels so much, because I know about the power they produce.

Based on the climatic data of the area, in the "International" building it is possible to place photovoltaic panels on the roof and facade of the building. Below is the solar radiation map of the building.

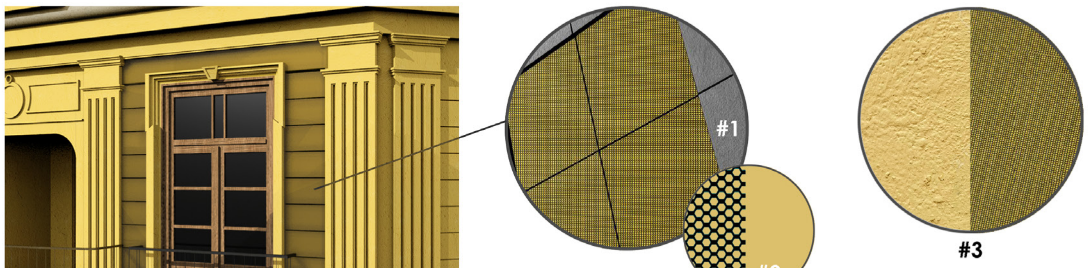


9) Based on the above map, the following image can be successfully implemented based on electricity generation in the building. What is your opinion on the picture below?

o I accept the change, knowing the benefits of photovoltaic panel.
o I do not accept the change because the image of the building is altered.
o I have no preference for mounting photovoltaic panels.

10) In the pictures below, the two color versions of the "International" building restoration are presented with the addition of photovoltaic panels on the first floor. Which of the two versions do you consider the most appropriate?

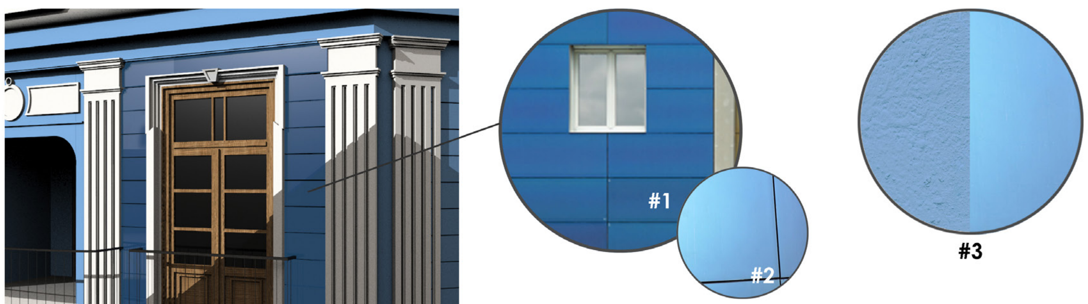
Option 1



#1: PV module
#2 : Detail of pv module surface

#3: Material variant of pv module

Option 2



#1: PV module
#2 : Detail of pv module surface

#3: Material variant of pv module

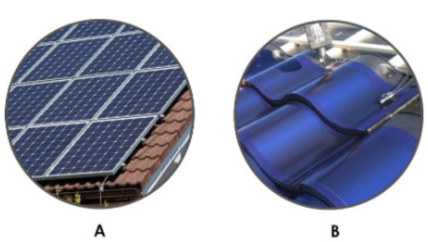
- o First choice
- o Second choice
- o None of the above

11) In the image above you can see a difference in quality of material (colored plaster and glass as the outer surface of the photovoltaic).
The difference in quality of material ...

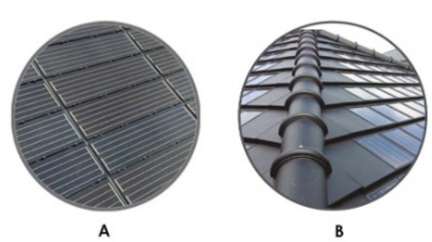
- o .... is clearly visible but does not affect the overall appearance of the building.
- o .... is not clearly visible and does not affect the overall appearance of the building
- o .... is clearly visible and affects the overall appearance of the building.

12) The following image shows some of the candidate photovoltaic options for mounting on the roof of the building.
The difference between the columns is the size of the photovoltaic: Column A _ panel, Column B style "tile". The rows represent three different color renditions.
Which one do you prefer?

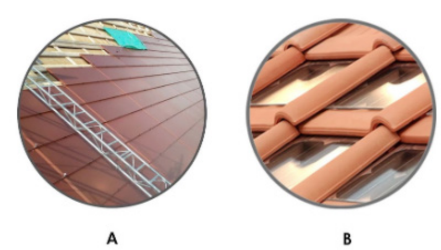
Choice 1



Choice 2



Choice 3



13)Based on your previous answer, answer the reason for your choice in the box.

4. Matrix Design Calculations

			Design # 1	Design # 2	Design # 3	Design # 4
Application Area						
	Roof_Sloped Surface					
		Average sunlight intensity(kWh/m2/day)	4.64 kWh/m2/day	4.64 kWh/m2/day	4.64 kWh/m2/day	4.64 kWh/m2/day
		Choice of PV	slate module, monocrystalline cells, size 487 x 296 mm, color terracotta-like, low reflectance	terracotta tile with colored cell , size 487 x 296 mm, low reflectance	slate module, monocrystalline cells, size 487 x 296 mm, color grey, low reflectance	wave solar tile (Hantile), thin film, size: 721 x 500 mm color:blue, low reflectivity
		Efficiency of PV (Wp/m2)	106 - 120 Wp/m2 , average 115 Wp/m2	164 Wp/m2	112- 160 Wp/m2, average 136Wp/m2	105 Wp/m2
		Efficiency of PV (%)	11.5%	16.4%	11.2 % - 16 % , average 13,6%	10,50%
		Surface area	156 m2 (1 190 active modules)	156 m2 (1 190 active modules)	156 m2 (1 190 active modules)	156 m2 (514 active modules)
		Temperature factor	0.41	0.41	0.41	0.41
		Active surface per module	90%	90%	90%	90%
		Energy Production per module	17.19 kWh annually	16.78 kWh annually	23.96 kWh annually	36.23 kWh annually
Total Production			20 456 kWh annually 20.4 GWh annually	19 968 kWh annually 19.9 GWh annually	28 512 kWh annually 28.5 GWh annually	18 640 kWh annually 18.6 GWh annually
	Roof_Flat Surface					
		Average sunlight intensity(kWh/m2/day)	4.64 kWh/m2/day	4.64 kWh/m2/day	4.64 kWh/m2/day	4.64 kWh/m2/day
		Choice of PV	slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity	slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity	slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity	slate module, monocrystalline cells, size : 1850x1200 mm, color grey, low reflectivity
		Efficiency of PV (Wp/m2)	112- 160 Wp/m2, average 136Wp/m2	112- 160 Wp/m2, average 136Wp/m2	112- 160 Wp/m2, average 136Wp/m2	112- 160 Wp/m2, average 136Wp/m2
		Efficiency of PV (%)	11.2 % - 16 % , average 13,6%	11.2 % - 16 % , average 13,6%	11.2 % - 16 % , average 13,6%	11.2 % - 16 % , average 13,6%
		Surface area	156 m2	156 m2	156 m2	156 m2
		Temperature factor	0,41	0,41	0,41	0,41
		Active surface per module	90%	90%	90%	90%
		Energy Production per module	321.25 kWh annually	321.25 kWh annually	321.25 kWh annually	321.25 kWh annually
Total Production			3 773.3 kWh annually 3.4 GWh annually	3 773.3 kWh annually 3.4 GWh annually	3 773.3 kWh annually 3.4 GWh annually	3 773.3 kWh annually 3.4 GWh annually
	Window Glazing					
		Average sunlight intensity(kWh/m2/day)	2.787 kWh/m2/day	2.787 kWh/m2/day	2.787 kWh/m2/day	2.787 kWh/m2/day
		Choice of PV	Amprphous silicon cells, 30% transparency, size 850 x 520mm (0.44 m2)	Amprphous silicon cells, 10% transparency, size 850 x 520mm (0.44 m2)	PV glass encapsulant, crystalline sillicon cells, high solar density (15 % transparency), size 850 x 520mm (0.44 m2	Amorphous silicon cells, 20% transparency, size 850 x 520mm (0.44 m2)
		Efficiency of PV (Wp/m2)	28 Wp/m2	40 Wp/m2	48.9 Wp/m2	34 Wp/m2
		Efficiency of PV (%)	2.8 %	4%	4.9 %	3.4 %
		Surface area	8 m2	8 m2	8 m2	8 m2
		Temperature factor	0,41	0,41	0,41	0,41
		Active surface per module	60%	80%	75%	70%
		Energy Production per module	4.9 kWh annually	9.35 kWh annually	10.74 kWh annually	6.9 kWh annually
Total Production			122.8 kWh annually 0.12 GWh annually	233.89 kWh annually 0.23 GWh annually	268.61 kWh annually 0.26 GWh annually	173.96 kWh annually 0.17 GWh annually

	Plaster					
		Average sunlight intensity(kWh/m2/day)	2.787 kWh/m2/day	2.787 kWh/m2/day	2.787 kWh/m2/day	2.787 kWh/m2/day
		Choice of PV	Dye Encapsulant module (Kromatix), size 240 x 550 mm (0.12 m2) color yellow, low reflectance	Ceramic Ink Pattern module (Colorblast), size 240 x 550 mm (0.12 m2) color yellow ochre, low reflectance	Dye Encapsulant module (Kromatix), size 240 x 550 mm (0.12 m2) color blue, low reflectance	Ceramic Ink Pattern module (Colorblast), size 240 x 550 mm (0.12 m2) color blue, low reflectance
		Efficiency of PV (Wp/m2)	144 Wp/m2	80 Wp/m2	147 Wp/m2	150 Wp/m2
		Efficiency of PV (%)	14.4 %	8%	14.7 %	15%
		Surface area	18.8 m2 (106 modules)	18.8 m2 (106 modules)	18.8 m2 (106 modules)	18.8 m2 (106 modules)
		Temperature factor	0,41	0,41	0,41	0,41
		Active surface per module	90%	90%	90%	90%
		Energy Production per module	16.79 kWh annually	11.09 kWh annually	20.39 kWh annually	21.5 kWh annually
Total Production			1 780 kWh annually 1.78 GWh annually	1 176kWh annually 1.17 GWh annually	2 2162kWh annually 2.21 GWh annually	2 179 kWh annually 2.18 GWh annually
	Shutter Surface					
		Average sunlight intensity(kWh/m2/day)	2.787 kWh/m2/day	2.787 kWh/m2/day	2.787 kWh/m2/day	2.787 kWh/m2/day
		Choice of PV	Thin film cells, color golden brown, low reflectivity	Thin film bi-facial cells, color golden brown, low reflectivity	Thin film cells, color golden brown, low reflectivity	Thin film bi-facial cells, color grey, low reflectivity
		Efficiency of PV (Wp/m2)	120 Wp/m2	156 Wp/m2	120 Wp/m2	156 Wp/m2
		Efficiency of PV (%)	12%	15.6 %	12%	15.6 %
		Surface area	4.33 m2 (325 modules)	4.33 m2 (325 modules)	4.33 m2 (325 modules)	4.33 m2 (325 modules)
		Temperature factor	0,41	0,41	0,41	0,41
		Active surface per module	90%	90%	90%	90%
		Energy Production per module	1 kWh annually	1.3 kWh annually	1 kWh annually	1.3 kWh annually
Total Production		Open position	328.65 kWh annually 0.32 GWh annually	427.25 kWh annually 0.42 GWh annually	328.65 kWh annually 0.32 GWh annually	427.25 kWh annually 0.42 GWh annually
		Close position	657.3 kWh annually 0.65 GWh annually	854.5 kWh annually 0.85 GWh annually	657.3 kWh annually 0.65 GWh annually	854.5 kWh annually 0.85 GWh annually