# SUSTAINABLE ROOFTOPS: PUBLIC SCHOOLS AND EDUCATIONAL FACILITIES IN BEIRUT

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# Abstract

As cities are growing today, various problems are appearing and created by this growth; and Beirut is no exception. The main outcome of this is investments in land for construction, which leads to lack of open spaces and especially green spaces. Beirut is suffering from the over crowdedness of people and buildings and most importantly the lack of green spaces. On the other hand, rooftops are usually large empty spaces that resemble mostly to the empty lots before the construction of their respective buildings, so they are an urban layer that can make up for the lack of open spaces in the city, not to mention that they are also exposed directly to the sunlight. Therefore, rooftops present an important potential in solving some of the problems created by the city growth, by being transformed into what we call "green" rooftops. This type of rooftop deals with two alternatives, according to research, either urban agriculture or energy generation. This research builds on a review of these two alternatives of "green" rooftop focusing on vegetated roof and its impacts on the community and the city and not only on the building itself. This research examines the specificities of urban agriculture for the city, explaining how, according to literature, this alternative can be applied, and why rooftops are an important asset for it. In addition, schools and educational facilities also present an important potential in this research; these facilities are considered a meeting point for various stakeholders in society such as students and instructors themselves, the parents, the neighboring buildings and the community. Also, their rooftops are mostly empty and not used for anything. In order to study the role of schools' rooftops in becoming "green", this research dives deeper into the school itself (its history, educational program, relation to the community, etc.) and its context. To do this, different schools are chosen for the study of this research, having different aspects, profiles and of course context. Accordingly, the vegetated roof is assigned to the schools' rooftops; and each roof is designed in a way to serve as a prototype for other similar schools.

# **Chapter 1-** Introduction

As cities are expanding, various problems are appearing due to this growth, and Beirut is no exception. From electricity shortage, traffic congestion, solid waste management, drinking water and wastewater management, urban heat island, high carbon emission, to even low production in local food, the overpopulation in Beirut has many negative impacts on the city (CES-MED, 2012). Beirut is suffering from the over crowdedness of people and buildings and the lack of green spaces.

This study inquires about the potential of existing rooftops in turning them into “green” ones. This would benefit communities in the vicinity of such buildings and the city at large by exploring the alternative of urban agriculture in vegetated roofs for food production. Moreover, the educational sector, being public schools and educational facilities, is chosen in this study to look closer at their rooftops and explore their values and potential, and also study their role as a meeting point for various stakeholders in the community and the city.

## 1.1. Setting the framework

Today, more than half of the world’s population live and work in cities, and it is estimated that by 2050, it will exceed two thirds of the world’s population (UNDP, 2020). According to the UNDP, the Middle East and especially the Arab region, which includes Lebanon, is also witnessing an urbanization growth with an average growth rate of 2.5% per year since 2015. Furthermore, according to UN-habitat in 2016, urban areas are responsible for consuming 60-80% of global primary energy, and generate up to 70% of the world’s total greenhouse gas emissions through the consumption of fossil fuels for energy supply, transportation and food production. (UN-habitat, 2016)

This urban growth has an important impact on the environment, at the city scale in general, and on the building itself (architectural scale) in particular. This research studies the impact of roof greening on the city (macro scale) and on the building itself (micro scale). Many environmental problems emerge due to this growth: air pollution, loss of green spaces, increase in energy generation and increase in demand in food production are the main ones (Torrey, 2004). According to a study done in 2017, the cities are growing and so is the demand on residential projects that meet the required needs of the users. In urban areas, the high demand on property has led to more densification in buildings and to a significant decrease in the green spaces around the city (Misni, 2017).

In addition, the World Bank stated in its “Development and Climate Change” report that the building envelope represents a great potential in which we can realize the savings from energy efficiency. The building envelope includes the roof, the walls, the windows, the doors and the insulation, while the roof is considered the element having the most potential. (WorldBank, 2010)

## 1.2. Statement of the problem

Several researchers (Sharanbir Grewal (2012); Daniel Haberman (2014); Francesco Orsini (2014)) have studied the potential of food production, each in their respective studies dealing with the economic (cost analysis) and the urban aspects, to address the increase in demand for it, through urban agriculture. While others (Jaroslav Hofierka, (2014); Miguel Amado, (2014); Francesca Poggi, (2014)) assessed the potential of renewable energy, also in their respective studies dealing with the engineering (electrical and mechanical), the architectural and the economic aspects, through PV system application in order to meet the urban energy needs. Both solutions require large areas to execute and also high exposure to sunlight. Therefore, rooftops are considered the most suitable element for these applications in urban areas where land is scarce, due to them being large unused areas with a direct exposure to sunlight. (Benisa, 2018) In Lebanon, this is the case of -if not all- many rooftops.

Since 2010, the awareness of urban farming and its benefits have risen, and many projects are being designed and constructed using rooftops and/or abandoned buildings in urban areas due to the lack of land availability (Thomaier, 2014). Furthermore, schools play a significant role in this subject, since their environmental and socio-educational aspects are not only exclusive for the students but also reach families and neighborhoods; therefore, transforming their rooftops into “green” helps in improving the metabolism and the economic cycle in compact cities such as Beirut. (Nadal, 2018)

## 1.3. Context

The comparison of Beirut to other metropolitan areas in the world in general, and in the Mediterranean area in particular, reveals that it faces similar problems regarding the rapid over growth and the increase in demand of land to build more. This urban growth leads to the loss of green spaces in the city, which in turn leads to several environmental issues such as mainly air pollution and increase in demand in food production. In addition, a shortage in energy supply has been happening since the 1990s at the end of the Lebanese civil war, so making use of rooftops in terms of energy generation can also help in addressing this problem.

Schools and educational facilities present an important potential in their rooftops, because most of them are vacant and not used for anything, so they can be transformed into rooftop greenhouses. In addition, educational facilities have the ability to unite different stakeholders with their interests into one element (students, families, teachers, neighbors, local community) (Nadal, 2018). Moreover, designing schools today should implement sustainability in the architecture, which is missing in the existing ones (Dianat, 2015); sustainability not only should affect the architecture of the school, but it also needs to be a learning tool for the students. (Ramli, 2012)

In order to study this in a thorough manner, this thesis will be focusing on the rooftops of the schools and educational facilities existing in the urban and sub-urban area of Beirut, dealing with the architectural aspect (design and use) of the implementation while basing the work on the three pillars of sustainability (the impacts of these rooftops on the economic, social and environmental aspects of the building itself, the community and the city of Beirut).

## 1.4. Purpose, Scope, Research Question and Objectives

This thesis aims to provide decision-makers in Lebanon with a methodology of analysis of alternatives suitable, sustainable for application on the rooftops of schools and educational facilities. These decision-makers include the superintendents in the educational sector, the ministry of education, the ministry of environment, and urban environment specialists. The research will investigate a methodology that is suited for different contexts and conditions of the educational facilities, which will benefit in turn the urban area around it. The rooftops of these schools will be assessed in their current condition, and accordingly propose a solution targeting the food production need through the application of vegetated rooftops (also considering the context and location), in order to have a more specified and direct scope of work.

The research questions for this study are:

How can existing school buildings' rooftops be reformed to become "green"? What is the impact on the school itself (the school being the building and the meeting point for various stakeholders in the community), and the city on a larger scale?

In order to answer these questions, the following objectives are defined:

- to explain how can an existing rooftop be transformed into a "green" one

This objective will be addressed in Chapter 2 with a review of literature on the transformation of a rooftop into a "green" one, and the significance of the educational sector in this subject.

- to understand the aspects of a "green" roof and its impacts on the building itself and the city

This objective will be addressed in Chapter 2 with a review of literature on the influences of the green roof on the building and the city, in order to come up with a list showing the benefits of green rooftops, and also the effects on the school building with its users and the community.

- to explore the two alternatives of energy generation and food production

This objective will be addressed in Chapter 2 with a review of literature, on the two alternatives and their benefits, that sets an association between their application and the context, in addition to assessing schools' rooftops conditions and transformations.

- to assess the state of agriculture and green spaces in Beirut through the years, in order to draw a conclusion about the need of green spaces in the city today

This objective will be addressed in Chapter 2 with a review of literature on Beirut's urban density and the reduction in green spaces around the city with maps of the area from 1980.

- to showcase the urban agriculture initiatives in Beirut vs. around the world

This objective will be addressed in Chapter 2 with a review of literature on initiatives concerning urban agriculture through a vegetated roof in local scale (Beirut) and international scale, while also comparing individual initiatives with NGO ones.

- to form a synthesis from the reviewed literature

This objective will be addressed further in Chapter 2 with a synthesis that gathers all the info collected, and informs a design of methodology and defines the types of data to be used.

- to address the three pillars of sustainability while focusing on the social and environmental aspects targeted in the two implementations

This objective will be addressed in Chapters 3 and 4, following Chapter 2's synthesis, with a statement of methodology and field work, where one of the two alternatives is applied on two schools' rooftop, and assessed according to the social and environmental aspects.

- to understand if the wind direction and velocity and the change in them can effect plant growth, and if yes how?

This objective will be addressed in Chapter 4, with a research that in order to validate the analysis results.

- to understand what types of crops are the most adequate to plant in the Mediterranean climate

  This objective will be addressed also in Chapter 4, with an additional research.

## 1.5. Structure of thesis

Regarding the structure of this thesis, it comprises five chapters including this introduction. Chapter 2, the literature review, will show, from different views, what is a "green" rooftop and how can an existing roof be transformed into a "green" one, while also presenting the impact of such rooftops on the community and the city according to the three pillars of sustainability. Furthermore, it will provide an analysis on schools' green rooftops around the world with similar context and climate conditions as Beirut. This chapter will be structured according to themes (sustainable roof: food production vs. energy generation).While chapter 3, the methodology, will be specifying the methods used to do the research and collect the data. Chapter 4 will discuss the results from the empirical work and analysis of data collected. Finally, Chapter 5 will be the conclusion of this thesis, answering the research questions and objectives and set recommendations for the future, while also addressing the various limitations faced in this study.

# **Chapter 2-** Literature Review

For the purpose to completely understand the "green" rooftop and its impact on the community and the city, and also the potential of schools and educational facilities' rooftops in this subject, various scholarly articles have been reviewed and analyzed to help further in the research and develop a proper summary of all the information present on the subject. Therefore, this chapter is composed of six main sections, each one dealing with an objective stated in the previous chapter, the introduction, while discussing how each one of the three pillars of sustainability is addressed in each objective. The first section states what a "green" rooftop is and explains the transformation of an existing roof into a "green" one, and shows why schools and educational facilities are considered a significant element for the rooftop transformation in cities. While the second section discusses the impacts of green rooftops on the building and the city on the social and economic levels, and how the "green" rooftop affects the school building with its users and the community. In the third section, the articles are chosen according to themes, dealing with two main alternatives found in abundance, of a "green" roof, either through energy generation or food production; here, schools around the world with similar context and climate as Beirut, and their design, will be discussed, focusing on their rooftops' conditions and transformations. Some articles discuss directly the topic, explaining the "green" roof and its impact, while others test the two applications through case studies by comparing, evaluating and reviewing them. The fourth section showcases the state of agriculture and green spaces around Beirut and how they have been decreasing in size since 1980. While the fifth section discusses the individual and NGO initiatives concerning urban agriculture in Beirut and around the world. Finally, the sixth section presents a synthesis from the reviewed literature, informing how the methodology for this thesis is designed and what types of data to be used.

## 2.1. A "green" rooftop: definition and aspects of transformation from a regular one

The International Conference on Climate Change in Kyoto in 1997, discussed the importance and necessity for governments around the world to improve in their countries' environmental performance, specifically in the air pollution and energy need aspects. The concept of sustainable development is encouraged to be applied mostly in the construction sector, having the highest percentage of energy waste, in order to attain the mentioned goals. (Hutchinson et al., 1999)

Hutchinson and Roberts state (1999) that the rooftop is the most challenging part in achieving the sustainability goals, being the most important element in the building's envelope due to its state of being directly exposed to all weather conditions. The roofing industry faces many challenges when it comes to securing the energy efficiency for the building. Therefore, the more improvement works are done within these challenges, the better the performance on the rooftop gets on the longer term. They also define the "green rooftop" meaning in their report as "a roof system that is designed, constructed, maintained, rehabilitated and demolished with an emphasis throughout its life cycle on using natural resources efficiently and preserving the global environment". (Hutchinson et al., 1999, p. 4)

Furthermore, Ugai explains what is meant by "green"; "it is a type of architecture that is environmentally friendly. Several interpretations of 'green' exist, with several ways to measure the validity of sustainable methodologies, or how 'green' a building is." (Ugai, 2016, p. 850)

However, if we take "green" in its literal meaning, Bitaab and Golestani (2018) state that a green roof is a space that allows plants and vegetation to grow on the rooftop of the building, a system that protects the outer shell of the roof and is composed of many layers that include the root protector and the drainage. Moreover, it is not only a green surface but also a living space for vegetative plants. (Bitaab et al., 2018)

Moreover, defining what a "green" rooftop is, or in other words sustainable rooftop, is a complicated process. Various definitions occur, such as describing the roof as either "cool" or "warm"; the first is associated with the application that absorbs the sun's heat, transforms it to energy and help the roof stay at a cooler temperature, while the second describes the vegetated roof where a new landscape is created (Elborombaly et al., 2015). Most often, sustainable rooftops are described by colors; 'white' to reflect the sun, 'blue' to capture rain and storm water, 'green' to allow plants to grow and 'black' to implement PV panels. (Hoff, 2011)

Therefore, defining a "green" rooftop is often times associated with its sustainability aspect, more than the literal meaning behind it; this is a roof that not only is energy efficient, but also produces clean energy, in addition to growing vegetation that produces crops and contributes to air purification in the city. There are various applications or alternatives for a sustainable rooftop, however, research shows that only two are the most popular for application, for they target various problems at once.

“Green” rooftops include two main alternatives, from the various other ones –vegetated (plant based) and energy efficient. The plant-based green roof has two categories being either extensive (plants for air purification) or intensive (plants that produce crops), with or without the construction of a greenhouse, and targets the urban food production need and air pollution problems in cities. Whereas the energy efficient green roof is a system of PV panels and rainwater harvesting, and targets the urban energy needs, and reduces both the storm water runoff and the city’s heat island effect. (Nasr et al., 2015)

### *2.1.1. Transformation of an existing roof into a sustainable one*

As for how an existing rooftop can be transformed into a green one, there are several steps to be taken. First, a number of questions need to be answered such as the access, exposure and stakeholders of the building and its rooftop, then, the type and construction of the building, and the relation to context (from neighborhood to community to city) (Nasr et al., 2015). Second, the rooftop state needs to be defined in terms of -and not specific to- area, construction type, orientation, roof tilt angle, location, shading, as well as other existing uses, such as air conditioning and heating installations, water tanks, elevator shafts, roof terraces, or penthouses (Ordonez et al., 2010). Third, the alternative is assigned to the rooftop according to the gathered data in the previous steps. For the plant-based green roof, further decisions need to be taken such as the usable area, the need of a greenhouse and its type of either extensive or intensive (Benis et al., 2018) along with any possible shading and construction limitations (Byrne et al., 2015).

Further details are discussed in Section 2.3. of this chapter that deals with the transformation of an existing rooftop to a sustainable one.

### *2.1.2. Significance of schools and educational facilities*

In addition, defining which rooftops in the city are the most suitable for the transformation has to do with the building use. Various researchers discuss that sectors, such as commercial, educational and administration are highly recommended due to the fact that they are mostly owned by a single stakeholder. (Wu et al., 2018)

According to Sanjuan-Delmas (2016) schools and educational facilities present an important potential in their rooftops, because most of them are vacant and not used for anything, so they can be transformed into sustainable roofs. In addition, educational facilities have the ability to unite different stakeholders with their interests into one element (students, families, teachers, neighbors, local community). Moreover, "at present, educational facilities play an important role in developing the sensitivity of students, families, and neighbors towards environmental sustainability and social cohesion, through educational activities related to food and urban agriculture" (Nadal et al., 2018, p. 1320)

## 2.2. Impacts of the "green" rooftop on the building, the community and the city

Most of the literature that addresses "green" rooftops, or sustainable rooftops state their impacts on the building itself, the community or neighborhood and on the city overall. This goes to show how important these rooftops are, that they have the ability to leave an impact not only on the architectural scale but also expanding to the urban scale.

Sustainable rooftops, in their two main alternatives, can affect multiple scales while addressing the three pillars of sustainability. Vegetated roofs are considered an economically and environmentally sustainable way of making-use of rooftops in the city, for they help in reducing the need of food transportation (food-miles) and in creating local job opportunities, not to mention of course that plants contribute significantly in reducing air pollution; while rooftops mounted with PV panels, provide clean energy, are cost-effective, and also offer job opportunities to various extents and depending on the context (Benis et al., 2018).

Shafique, Kim and Rafiq (2018) discuss the various effects of such rooftops on the building and the city. They have multiple benefits in

> Rainwater management, reduced urban heat island, increased urban plant, wildlife habitat and roof life, enhanced air and water quality and quality of life, decreased energy consumptions costs of the building, decreased noise pollution, procreated recreational activities and increased green areas in urban environments. (Shafique et al., 2018, p. 757)

In addition, Ugai (2015) lists various benefits of a sustainable roof. These benefits include reduction in energy consumption (Barrio, 1998), increase in sound insulation (Dunnett, 2004), reduction of urban heat island (Banting, 2005), storm water management (Stovin, 2007), improved urban air quality (Yang, 2008), and extension of roof life (Mander, 2009).

*2.2.1. Impacts of each alternative of sustainable rooftops*

Moreover, vegetated roofs have the ability to increase both the productivity and the efficiency of the crops produced in them. This, in turn, allows for the optimization of energy performance of the building, reduction of carbon dioxide emitted by the building, increased crop yield and minimization of external water use. (Sanjuan-Delmas, 2018)

Additionally, studies in the U.S., European Union, Canada and Spain show that widespread PV panels' applications could cover fifteen to forty five percent of national electricity consumption (Byrne et al., 2015).

*2.2.2. Advantages and disadvantages of vegetated rooftops*

Bitaab (2018) indicates the advantages and disadvantages of vegetated roofs; these roofs are good at reducing the effects of thermal islands due to the plants' ability in creating moisture and forming cool air (ZinCo Canada: Advanced Green Roof Technology, n.d.), they also clean the air by absorbing carbon dioxide and producing oxygen (Peck et al., 1999). Vegetated rooftops receive seventy five percent of rainfall and reduce excessive load on sewage system by adopting a sewage management method (Azerbayjan Architectur - BLOGFA, n.d.). They reduce the building's heating load by adding the mass and the thermal insulation layer, and cooling load through evaporative cooling (ZinCo Canada: Advanced Green Roof Technology, n.d.). Vegetated rooftops can be used as a recreational and resting space for the inhabitants of the building, therefore, creating a pleasant atmosphere in an urban life (Bitaab et al., 2018). Vegetated roofs have a positive effect on the social and mental aspects, where people share these spaces and rely on each other. These rooftops also improve the scenery of the building and around the neighborhood, they create a new landscape layer in the urban area, and increase the property value (Misni et al., 2017). Green roofs expand the life span of the roof membrane by protecting it from weather damage (ZinCo Canada: Advanced Green Roof Technology, n.d.). They contribute in repairing the natural cycle of life by reintroducing the biodiversity in cities, which is an important issue for urban environment

(Luckett, 2009). On the other hand, these rooftops can cause several problems such as subsidence, deposition of soft soil, drainage problem, hardening of surface layer of the soil, formation of ponds, root penetration, thick and heavy ceiling (Dabbaghian et al., 2009), in addition to structural problems due to the heavy loads, adaptation to climatic conditions, and the fact that they are not designed for human presence. (Bitaab et al., 2018)

Therefore, it is important to understand the pros and cons of such rooftops and their systems and applications, and select the one with the most benefits in its life cycle, while keeping maintenance of the different elements of the system. (Ugai, 2016)

### *2.2.3. Schools' rooftops in the city*

As for the educational facilities in general, the existing school buildings and programs do not meet the needs for sustainability and established learning environments through practices for students; they need to be upgraded and this can be solved by transforming their vacant rooftops into usable sustainable spaces that generate energy and/or produce crops (Dianat et al., 2015). To note that there are two types of schools, public and private, therefore this upgrade process differs depending on the school type which defines its abundant or limited resources to implement what this study proposes.

Ramli (2012) states that the most influential element in the educational program should target the sustainability concept and practice (Ramli et al., 2012). In addition, the school's environment (building and program) affects the student's achievements (Rudd et al., 2008), therefore, implementation of sustainability practices such as agriculture and PV panels would cause a greater understanding in students about the need for sustainability and its benefits, not to mention also that it will lead to a better environment for living and learning (Stankovic et al., 2015).

## 2.3. "Green" rooftop: Energy generation or food production

Significant literature is available on the two main alternatives of sustainable roofs in urban areas –energy generation and food production (Collier et al., 2013) (Byrne et al., 2015) (Dimond et al., 2017) (Benis et al., 2018) (Corcelli et al., 2019). Most of them examine each of these two alternatives separately, while only some analyze both of them by comparison and explore also some case studies for both. Furthermore, there is a lot of research done on vegetated roofs for food production in cities, much more than on energy efficient roofs mounted with PV panels that aim to generate energy and reduce excessive consumption. In this section, I will discuss both topics while reviewing the different case studies pertaining to them.

### *2.3.1. Energy generation*

Several international organizations are encouraging city energy economy restrictions as an important tool to meet sustainable development goal in cities, such as the World Bank, the United Nations Development Program (UNEP), and the Organization for Economic Co-operation and Development (OECD) (Byrne et al., 2015). The rooftop real estate is a key-interest in this subject, for it is mostly unused and can allow for the widespread application of photovoltaic (PV) panels that capture solar radiation and transform it into energy to be used in buildings such as electricity. Therefore, the adoption of PV applications on rooftops in cities would lead in lower energy consumptions and waste (Byrne et al., 2015). In addition, "the installation of building-integrated photovoltaic systems is a viable option for the achievement of energy sustainability." (Ordonez et al., 2010, p. 2123)

Distributed PV applications on rooftops in cities is largely executed on roofs that can be refurbished, therefore, they require minimal pre-designed roofs. (Wu et al., 2018)

Amado and Poggi (2013) state that in order to slowdown climate change and reverse the excessive consumption of energy in buildings, energy efficiency measures through renewable energy resources are important. This will lead to Net-zero energy buildings, where a building consumes energy just as much as it produces (here, rooftops are a tool to achieve such goals). Looking at a larger scale, Net-zero buildings along with a planned energy grid lead to having a Net-zero neighborhood, which in turn leads to a low-carbon system, pushing the city towards achieving sustainable development goals. (Amado et al., 2013)

### *2.3.2. Food production*

First, urban agriculture is a concept discussed in great abundance in literature, and is defined by many categories such as vertical farming, Z-farming (Despommier, 2010) and Skyfarming (Specht et al., 2014). It is basically food production in buildings in cities, in order to meet the need of food for the overpopulated urban areas and create new local job opportunities. (Thomaier et al., 2014)

According to the Association for Vertical Farming (2016), "vertical farms are classified depending on the level of integration with the building, for example, by the placement (rooftop, facade), exposure (exposed, enclosed, closed), growth medium (aeroponic, hydroponic, aquaponic) and production purpose (educational, research, commercial)" (Sanjuan-Delmas, 2018, p. 327)

Unused roofs in cities have a great potential to be used for urban agriculture (Rodriguez, 2009). This approach is becoming more of a standard in several countries around the world, such as New York (Ackerman et al., 2012), Singapore (Deng et al., 2012) and Montreal (Haberman et al., 2014). As also noted by Sanye-Mengual (2015), vegetated rooftops are being widely applied as experimental project in the Mediterranean areas due to their climate conditions that are beneficial for vegetation and growing crops. (Corcelli et al., 2019)
Orsini (2014) takes the city of Bologna in Italy as a case study for urban agriculture, where seventy seven percent of its vegetable need grown in rooftop farms is fulfilled (Orsini, 2014). Sanyé-Mengual (2015) took Barcelona, in Spain, as a case study, and found that thirteen hectare of suitable rooftop area could produce two thousand tons of tomatoes annually, which could feed one hundred and fifty thousand people (Sanyé-Mengual et al., 2015).

As Thomier, Specht and Henckel explain (2014), "one approach is building-integrated agriculture, which means greenhouse systems on buildings, to exploit synergies between buildings and agriculture. At the opposite end of the spectrum, there are open, soil-based rooftop farming projects that often employ less sophisticated growing methods." (Thomaier et al., 2014)

Open soil-based roofs are distributed among four categories, which are intensive, semi-intensive, single-course extensive and multi-course extensive. This classification is according to the type of vegetation used and the thickness of soil which defines the type of irrigation (GSA, 2011). Intensive categories have thicker soil layers (6-12in and above) and require maintenance and irrigation. Extensive categories have thinner soil layers (3-6in) and rely on the rainwater for irrigation, therefore require less maintenance. (Shafique et al., 2018)
Furthermore, Sanjuan-Delmas (2018) examined a case study based on a building in the Universitat Autonoma de Barcelona campus (Spain), which is a research center composed of six floors and its rooftop is covered and constitutes of four areas of which one area is designated to implement an integrated rooftop greenhouse (i-RTG). Irrigated primarily by rainwater, and planted in total of one hundred and seventy tomatoes, the pilot i-RTG was monitored for a year,

and produced approximately twenty kilograms of tomatoes per m2 per year, in addition to the increase in energy savings it caused due to its natural irrigation. (Sanjuan-Delmas, 2018)

*2.3.3. Comparison of the two alternatives*

Both alternatives have several benefits for the building, the community and the city, and target the three pillars of sustainability (social, environmental and economic). However, studies show that choosing one or the other need to be done according to a study plan, and therefore, it is necessary to compare both alternatives and not to study them separately. (Dimond et al., 2017)

Collier and Wang (2013) compared vegetated roofs and PV mounted roofs, focusing mainly on the method being applied for sustainable goals, rather than the systems themselves (Collier et al., 2013). While Benis and Turan (2018) discussed the comparison of both applications through a cost-benefit analysis for each system, by assessing four scenarios of transforming existing roofs into sustainable ones (open-air food production; low-tech greenhouse farm; high-tech greenhouse farm; photovoltaic systems) (Benis et al., 2018). Corcelli and Fiorentino (2019) compared the two implementations by conducting a life-cycle analysis on each, from raw material extraction to end-of-life (Corcelli et al., 2019). Dimond and Webb (2017) addressed the comparison of the two alternatives by understanding the environmental and contextual factors in regards of their sustainable performance, considering their strengths and weaknesses at various scales of context (Dimond et al., 2017).

According to Wu (2018) the study of the context is necessary from the perspective of sustainable development. The location has an important impact on the cost of the application, and if chosen wrongly it could lead to a failure in the system and a non-optimal effect on the sustainable goals of the community and the city. (Wu et al., 2018)

Many approaches need to be considered as study plans in order to decide which alternative is suitable for the existing rooftop. However, since context is the most important element in the pre-design and decision-making phases, it needs to be studied carefully in order to choose the most fitting alternative that will benefit not only the building itself (building and users), but also the community and city.

Moreover, this research focuses on the urban agriculture alternative since it is way more present and discussed in literature, and also many initiatives have already been happening in Beirut as will be shown in section 2.5., so this research can add to that.

#### *2.3.4. Schools and educational facilities' rooftops*

In addition to the social and environmental opportunities, schools and educational facilities have a great potential in their rooftops, due to their structural-architectural characteristics. Their rooftops, being large and mostly vacant, represent an important aspect in adopting sustainable rooftops execution in urban areas (Nadal et al., 2018), which is an essential requirement for both alternatives (PV panels for energy generation and vegetation for crops production).

Furthermore, schools oftentimes have prime locations in neighborhoods, their rooftops are often made of strong structure such as reinforced concrete slabs that can hold additional loads, and educational facilities, such as universities, usually have kitchens and dining rooms where the crops produced on the roof can be consumed or organized to be distributed later on. (Al-Otaibi et al., 2015)

## 2.4. Beirut agriculture and green spaces: A historic overview

Sixty percent of the urban population of Lebanon lives in the city of Beirut alone (the municipal area and the suburbs) to an extent that Beirut holds almost five times the population of the second largest city in Lebanon, Tripoli. Beirut's population grew fast since the last century when it was barely six thousand, today it reached almost two million (Rishani, 2011). The growth in Beirut went through stages as figure 1 shows over the years of 1876 until 1996, while figure 2 presents the old Beirut in 1870s (view from AUB) showing the abundance of green spaces in the city back then.

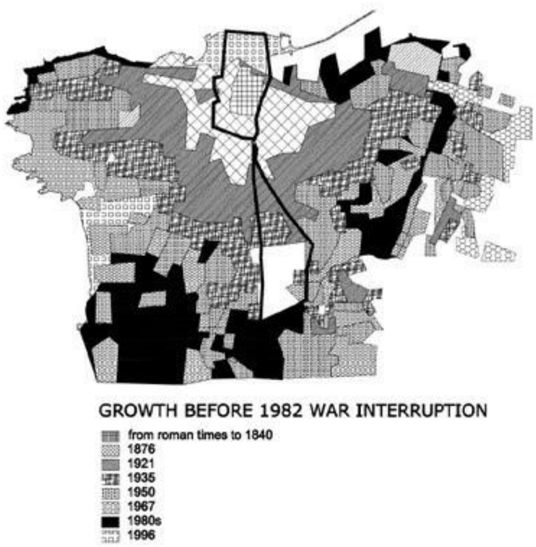


Figure 1 - Growth of Beirut from 1876 to 1996


Figure 2 - Beirut in 1870s (view from AUB)

The following maps are extracted from different sources showcasing Beirut over the years, from the most recent to the oldest found (2020-2015-1980), and the loss of green spaces in it due to the rapid overgrowth:

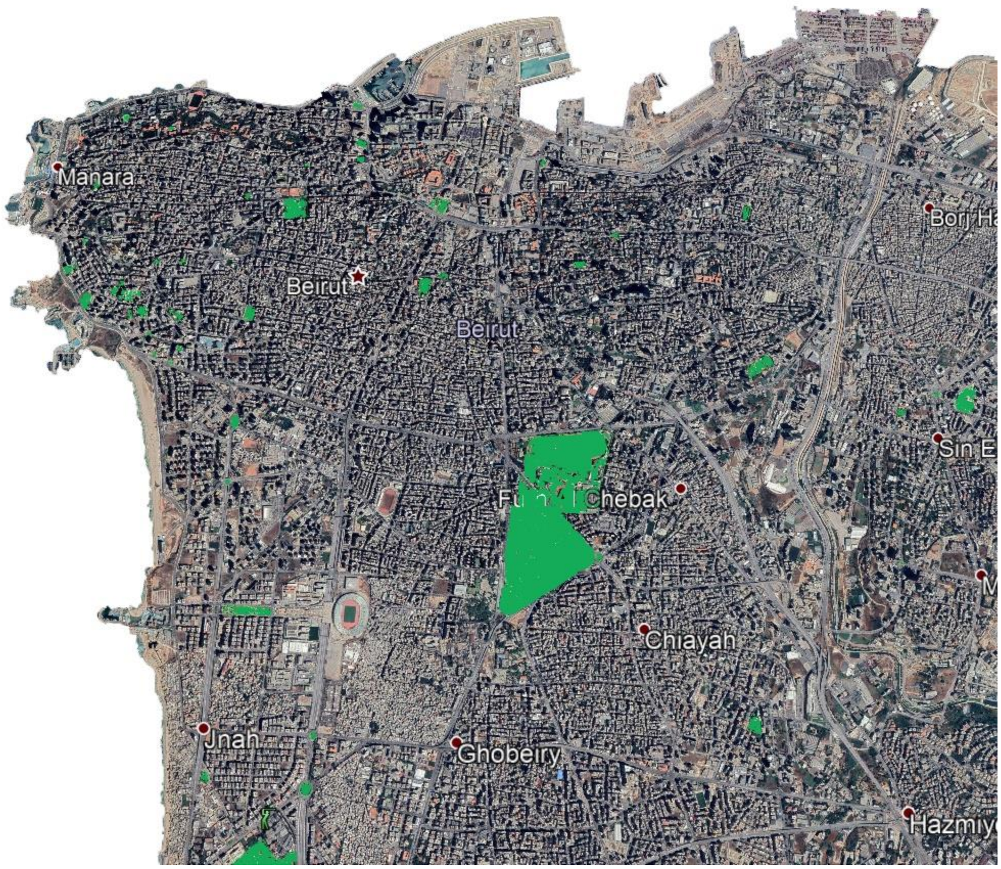



*Figure 3 - Beirut 2020 (Google Earth): highlighted in green are the green areas that are left today*

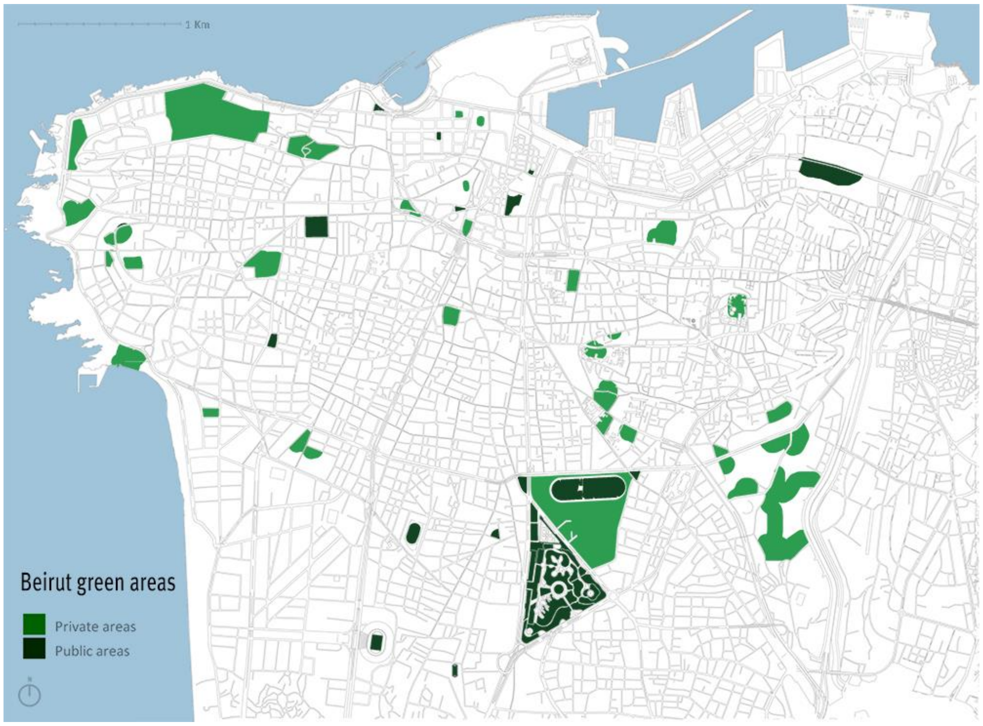



*Figure 4 - Extracted from AUB Neighborhood Initiative (2015): highlighted in green are the green areas left in Beirut private and public*

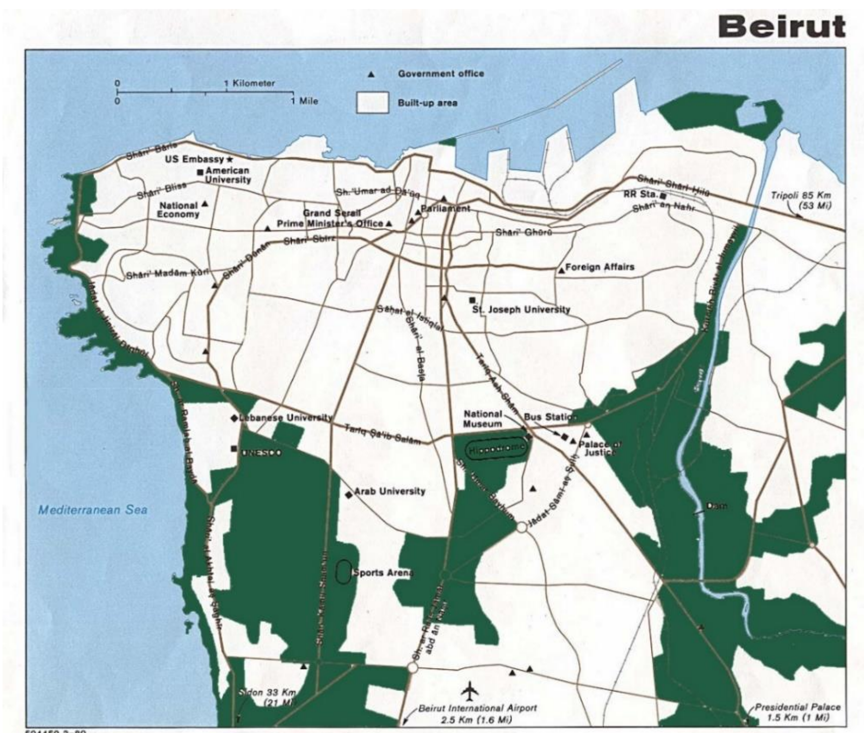



*Figure 5 - Beirut 1980 (lebguide.com): highlighted in white are the built-up areas vs. the green areas that were left intact back then.*

The case of urban agriculture in the city:

The uncontrolled and unplanned overgrowth transformed Beirut's suburbs into informally urbanized areas, therefore the urban agriculture that once existed in the outskirts of Beirut has completely vanished today and turned into built up areas. The few urban agriculture areas left are located in the southern suburbs, in Chouifat, Hay al Selloum, the Nahr Beirut area, the Sin el Fil area and Daychuniyyeh Valley. The largest of which is Hay al Selloum - Chouifat edge. (Figure 3) (Rishani, 2011)

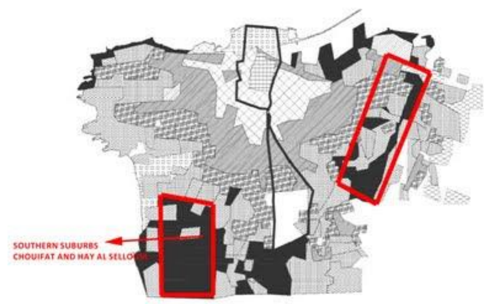



*Figure 6 - Left agriculture areas in Beirut today*

According to Rishani in her blog post,

> "Hay El Selloum, a neighborhood in the southern suburbs of Beirut which is an informal settlement that grew from an olive grove to one of the densest neighborhoods in Lebanon. The area houses about fifteen percent of the population of Beirut today." (Rishani, 2011)

## 2.5. Rooftop agriculture initiatives in Beirut vs. around the world:

As shown in the previous section, the overgrowth in Beirut over the years has led to the decrease in green areas in the city and particularly agricultural areas. Therefore, there is a concern about the lack of green spaces in Beirut expressed by different NGOs and many individuals. In order to study the current state of agriculture in Beirut today furthermore, research is done to find out if there are any initiatives concerning rooftop agriculture (since there are no more empty spaces around the city as explained in the previous section) and assess how developed they are, while comparing them to initiatives around the world. Reviewed literature show that rooftop agriculture initiatives around the world have been taking place in the last ten years or so, due to the rising need to have more sustainable green buildings and cities that can serve the future generations, as explained in

2.5.1, while in Beirut some new initiatives have started only in the recent couple of years due to the economic crisis that is taking over Lebanon, which led to a serious food security issue, as explained in 2.5.2.

### *2.5.1. Initiatives on the international level*

Urban agriculture is becoming more popular in various cities around the world due to the growing need of healthy, local food. Developed cities such as Bologna (Italy), Chicago (USA), Cleveland (USA), Hong Kong (China), Montreal (Canada), New York (USA), Portland (USA), Seattle (USA), Shanghai (China), Taipei (Taiwan), Tokyo (Japan), Toronto (Canada), and Vancouver (Canada), are relying on urban agriculture initiatives in order to meet the needs of food availability of the overgrowing number of inhabitants, which is not an easy task. Several factors control this process, including available land to grow crops, size and scale of the initiative, revenue generation potential, postharvest handling, and distribution methods. (Walters et al., 2018)

There is a growing interest in utilizing roof space for urban farming using green roofs strategies. Due to the fact of being left as unusable spaces in the city, the rooftops are being reclaimed for producing food. Figure 8 shows an example of a rooftop farming in a school in Hong Kong, which consists of a container garden shown on the left and a shallow raised bed on the right. (Hui, 2011)

*Figure 7 - Rooftop farm on a school in Hong Kong*

In New York City, there are over one thousand community gardens and around fifteen to thirty farms, depending on the definition of the term, many of which are identified on figure 10 which is a map prepared by Ackerman et al in their report in 2012. Moreover, "there are a number of organizations that support urban agriculture in NYC, including the Green Guerillas, Just Food, the

New York and Brooklyn Botanical Gardens, and, perhaps most prominently, GreenThumb, which is a critical program of the NYC Dept. of Parks and Recreation." (Ackerman et al., 2012, p. 11)

*Figure 8 - Map of rooftop farms in NYC, (Ackerman et al., 2012, p. 13)*

In addition, an important benefit, stated by both practitioners Nahid and Ahmed in Dhaka city, is increased interaction with neighbors. Non-practicing neighbors visit their garden due to it being one of the very few green spots near them in the city, and to also seek suggestions from them. It also increases the community bonding among them. (Safayet et al., 2017)

Furthermore, a research was conducted by Kumar, Natasha, Suraj and Manahar in 2019, in an urban corridor of Pokhara city in Nepal where rooftop farming started becoming more popular since 2018. The areas of Nagdhungha and Birauta have the highest number of enlisted practitioners, which means inhabitants who practiced urban farming, according to the database of Pokhara metropolitan city. For example, Gayatri Aryal is a housewife who started growing vegetables on her roof using her basic knowledge and eighteen dollars approximately. At first, she started the roof farming with basic plants like onions, garlic, and coriander, then two years later after getting support from District Agriculture Office, she got knowledge about cultivation practice of other vegetables like brinjals, tomato, chillies etc. another example is Damar Subedi who is the president of a community cooperative. His initial cost of the rooftop gardening was thirteen dollars approximately, growing species and flowers like petunias and marigold, then later he started incorporating vegetable growing also. (Kumar et al., 2019)

Meanwhile, in Dhaka city in Bangladesh, Shahnaz Rahman Nahid started roof gardening in 2011. The initial cost was only thirteen dollars with some guava trees and many flowers. A year later, the fruits and vegetables replaced flower plants. Nahid was trained in 2013 under the project of "Integrated Quality Horticulture Development Project" on rooftop gardening, in order to become a successful practitioner. While another practitioner, Khorshed Ahmed initiated the rooftop farm back in 2004. The initial cost was about twenty five dollars. Same as Nahid, Ahmed started by planting ornamental and flower trees, and two years later started planting vegetables and fruits in order to have access to fresh food. (Safayet et al., 2017)

#### *2.5.2. Initiatives on the local level*

However, in Lebanon the case is a little different as Tawfik explains in his blog post that

> "While in some cities people have become urban gardeners as a kind of cognitive therapy during the lockdown, urban gardening in Beirut is a prompt response to encounter a food

> crisis. In a country with twelve percent of arable land and a mild climate suitable to every crop, Lebanon hasn't put as much attention to food corridors as its well-known cuisine. Lebanon imports eighty percent of its food. The economic crisis has brought to the surface a serious food security issue." (Tawfik, 2020)

An economic crisis has hit Lebanon towards the end of 2019, which caused a rising interest in agriculture among Lebanese who felt the need to be food independent (being able to provide food for one's self and community), especially the inhabitants of Beirut where the overgrowth of the city is exhausting all available resources and depending on deported food more and more every day. This interest was manifested at individual and community levels, with individual initiatives that are most funded and supported by NGOs. 'Kon', is a neighborhood food growing initiative in Furn el-Chebbak that was developed in early 2020. (Rahhal, 2020)

'Retroact' is also a new urban agriculture initiative that basically aims to distribute plants and seeds to inhabitants around Beirut in order for them to plant them on their rooftops and balconies and be able to overcome the recent economic crisis. In his interview with Tawfik, Patrick Geara, an urban activist behind this initiative, explains the motive which is that it is way cheaper to grow one's food than to buy it from the market nowadays. (Tawfik, 2020)

Another famous initiative in Lebanon is 'Zarri3et Albi' which translates to 'the seed of my heart', a recent civil society campaign led by Nadine Labaki (a Lebanese writer and director) that aims to encourage urban agriculture in Beirut and its suburbs. This initiative also rose due to the recent economic and food security crisis. (AbdulBaki, 2020)

Jafra foundation, a local NGO, runs its own initiative concerning urban agriculture on rooftops and balconies in the city in an effort to diminish the danger of the recent food security crisis. Funded by this NGO, farms have been created around Beirut, on rooftops mostly, such as the farm ran by Omar Abu Zeinab on the rooftop of an office in Burj al Barajneh camp in the suburbs of Beirut, where various crops grow such as potatoes and other seasonal greens. Figure 7 shows the mentioned farm and Abu Zeinab working. (Newsom, 2020)

*Figure 9 - Omar Abu Zeinab in his Burj al Barajneh camp rooftop farm*

In addition, any residents of Beirut and its suburbs have turned their balconies and rooftops into small scale farms of vegetables to fight the economic crisis they are living. (Naamani, 2020)

In a part of Beirut, surrounded by high buildings, Souad Abdallah has started growing various plants on her rooftop, such as tomatoes and seasonal greens. Hadi Deaibes and Dahna Abou Rahme, form the agriculture collective Kon, help Abdallah construct a wooden bed for planting. (Figure 9) (Gustafsson, 2020)

*Figure 10 - Abdallah in her rooftop garden in Beirut*

Abdallah explains her motive for this initiative in an interview with Gustafsson by saying that “it all started during the revolution. I felt the need to do something constructive. I wanted to work with the community and invest in something sustainable. We follow permaculture philosophy and take into consideration the surroundings. We use compost soil and grow what can be grown in the city.” (Gustafsson, 2020)

In another part in Beirut, fifty year old Lebanese Manal Addada also transformed her rooftop into a garden where she grows plants including greens and tomatoes in order to secure her need of food in the upcoming months of the economic crisis. (Naamani, 2020)

Beirut is slowly being transformed into a green city, relying mostly on individual initiatives, as inhabitants are nowadays turning their empty rooftop into small gardens, in order to grow various fruits and vegetables such as potatoes, radishes, carrots and lettuce, tomatoes and cucumbers. In his interview with Artamonov in 2020, Michel explains the process of how his small rooftop garden, that he started only a year ago, has approximately doubled in size as the number of beds increased to accommodate more plant crops. This is all due to the recent economic crisis that Lebanon is witnessing since March 2020. (Figure 11) (Artamonov, 2020)

*Figure 11 - Michel in his rooftop garden in Beirut*

As for Geara and his team of 'Retroact' in Beirut today, they have experienced firsthand the social benefits of urban agriculture. The process of planting and maintenance have brought families and neighbors together and strengthens their bond more and more daily. In his interview with Tawfik, Geara adds that they "have seen groups working collaboratively and social bonds being reinforced through shared agriculture practices." (Tawfik, 2020)

## 2.6. Synthesis

From the reviewed literature, several assumptions can be made. “Green” rooftops are in another word sustainable rooftops, and have many alternative applications, among which there are two main ones that target several problems at once, the PV panels to generate energy and growing vegetation to produce food. There are several benefits of a sustainable rooftop for its building and users, the neighborhood where it exists, the community and the city, and these benefits target the three pillars of sustainability (social, environmental and economic) on various levels (architectural scale and urban scale).

In order to specify which alternative from the two is the most fitting for an existing rooftop, the context needs to be studied, and that means the building (construction type, condition, rooftop area and height, materials), neighborhood and surroundings (shading buildings, exposure to sunlight) and finally the city (skyline, climate, urban heat island).

Beirut’s agriculture and green spaces have been diminishing in size since 1960s (and well before); this is a problem that needs to be addressed and solved soon in order to reverse the negative impacts on the city and its inhabitants. Various initiatives have already started concerning urban agriculture in Beirut city on empty rooftops, on individual level and NGO level.

Therefore, Chapter 3, the methodology, will build on this synthesis to study the context in a thorough manner for the empirical work and data collection. In addition, this conducted literature review also informs what type of data will be used in this thesis.

# **Chapter 3-** Methodology

This thesis investigates rooftops of public schools in Beirut, their potential to become sustainable, by growing vegetables in order to produce crops, and their impacts on the building, the users, the community and the city overall. This chapter introduces the research methodology used for this study, and how it will guide the different phases of the research such as data collection, analysis and case study. Essential background and fundamental guidelines are provided in terms of parameters that define the green rooftop as a 'public space'; these parameters are common through different sources of literature discussing the same topic. The following six sections describe the types of data needed in mapping, the empirical work and the tools used for analysis. The first section describes the process of the collection of maps and data about public schools in Beirut, and how all the information overlap in order to choose the schools under study, which is described in section 3.2. The third section focuses on the empirical work and how it is conducted, while the fourth section specifies the analysis tools used in this study such as softwares. Section 3.5 presents the various limitations faced by this study along its process, and the sixth section discusses the parameters extracted from different literature to measure the value of "green rooftops as public spaces in the city". Finally, a conclusion summarizes this chapter and introduces the next one.

## 3.1. Mapping

Since no data was allowed to be accessed from the Municipality of Beirut in terms of cadastral maps of the area where the schools are highlighted, maps had to be redrawn and more information about schools had to be researched more from different source.

Database from the UNICEF[1] was accessed and it provided this research with an excel sheet showing only the existing public schools in municipal Beirut, their names and their coordinates on Google Maps (Figure 19).

[1] UNICEF: United Nations International Children's Emergency Fund.

Other online database[2] has provided a 3D model of municipal Beirut drawn in Rhino, which is a 3D modeling software, in 2019. The model shows the area of municipal Beirut with its topography, buildings and streets.

Information about public schools from UNICEF was projected on the 3D model of Beirut in Rhino, by finding the exact location of the school on Google Maps using the coordinates of each school, and then highlighting the building of the school in color red on the 3D model as shown in figure 13.

Google Maps provided also information about the left green spaces in Beirut in 2020. Figure 14 shows the map extracted from Google Maps showcasing this.

In addition, UNV[3] has provided a map (figure 15) showing the approximate impact of Beirut blast that occurred in August 4th, 2020, which will be discussed furthermore in the Limitations, section 3.5.

[2] Salim Al Kadi – Architect: has drawn a 3D model of municipal Beirut, in 2019, on Rhino showing the topography, the buildings and streets of the area. The file can be accessed through: http://www.salimalkadi.com/07_beirut-001

[3] UNV: United Nations Volunteers: https://www.unv.org/Multimedia/Beirut-disaster-volunteers-lead-community-support-and-recovery-efforts

| 1 | CERD | Governorate | Caza | Cadaster | CAS Code | School Name | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| 2 | 1 | Beirut | Beirut | Achrafieh fonciere | 10650 | Uruguay First Achrafieh Public School for Boys | 33.87902908 | 35.5297956 |
| 3 | 2 | Beirut | Beirut | Achrafieh fonciere | 10650 | El Tabaris El Namozajia for Girls Public School | 33.88715323 | 35.52555367 |
| 4 | 4 | Beirut | Beirut | Rmeil fonciere | 10550 | Achrafieh Third Mixed Intermediate Public School | 33.89609422 | 35.52662667 |
| 5 | 5 | Beirut | Beirut | Achrafieh fonciere | 10650 | El Achrafieh First for Boys Secondary Public school | 33.883729 | 35.517655 |
| 6 | 6 | Beirut | Beirut | Achrafieh fonciere | 10650 | El Achrafieh Second Secondary Public School | 33.88418415 | 35.5173746 |
| 7 | 7 | Beirut | Beirut | Achrafieh fonciere | 10650 | Salma El Sayegh Public School for Girls | 33.8852892 | 35.51694361 |
| 8 | 8 | Beirut | Beirut | Achrafieh fonciere | 10650 | Lor Mghayzil for Girls Secondary Public School | 33.889882 | 35.528374 |
| 9 | 9 | Beirut | Beirut | Achrafieh fonciere | 10650 | El Achrafieh Mixed Intermediate Public school | 33.891454 | 35.528722 |
| 10 | 10 | Beirut | Beirut | Achrafieh fonciere | 10650 | Karm El Zeitoun Mixed Intermediate Public School | 33.888968 | 35.526453 |
| 11 | 12 | Beirut | Beirut | Mazraa fonciere | 10310 | Beirut Alaliya Girls Intermediate | 33.88543323 | 35.50025069 |
| 12 | 13 | Beirut | Beirut | Bachoura fonciere | 10350 | Al Mousaitbeh Public School for Boys | 33.88650822 | 35.50157068 |
| 13 | 14 | Beirut | Beirut | Bachoura fonciere | 10350 | Houd Alwilaya First Mixed | 33.8892992 | 35.50117061 |
| 14 | 15 | Beirut | Beirut | Bachoura fonciere | 10350 | El Mostakbal Mixed Public School | 33.88934422 | 35.50077266 |
| 15 | 16 | Beirut | Beirut | Zqaq el Blat fonciere | 10410 | Zoqaq AlBlat Mixed | 33.89289389 | 35.49854294 |
| 16 | 17 | Beirut | Beirut | Mazraa fonciere | 10310 | For Girls Second Public School | 33.88139919 | 35.50067069 |
| 17 | 19 | Beirut | Beirut | Bachoura fonciere | 10350 | Mufti Shahoed Hasan Khaled Secondary | 33.88869919 | 35.50007062 |
| 18 | 20 | Beirut | Beirut | Mazraa fonciere | 10310 | Burj Abi Haidar Mixed Public Kindergarten | 33.877361 | 35.505001 |
| 19 | 21 | Beirut | Beirut | Msaitbe fonciere | 10210 | Wata Al Mousaitbeh Mixed Public School | 33.8946144 | 35.49100039 |
| 20 | 22 | Beirut | Beirut | Msaitbe fonciere | 10210 | Zahia Salman Secondary Public School (formerly Wata El Msaytbeh) | 33.87659915 | 35.4917706 |
| 21 | 23 | Beirut | Beirut | Msaitbe fonciere | 10210 | Namouzajiya Mixed Public School | 33.86839919 | 35.49317064 |
| 22 | 24 | Beirut | Beirut | Mazraa fonciere | 10310 | Fakhreddine El Maani Secondary Public School for Girls | 33.88319915 | 35.5010706 |
| 23 | 25 | Beirut | Beirut | Mazraa fonciere | 10310 | King Saoud Girls Intermediate | 33.88209917 | 35.50147068 |
| 24 | 26 | Beirut | Beirut | Mazraa fonciere | 10310 | Al Irshad Public School for Girls | 33.88216924 | 35.49908068 |
| 25 | 27 | Beirut | Beirut | Mazraa fonciere | 10310 | Mazraa First Boys Intermediate | 33.88109923 | 35.5014707 |
| 26 | 29 | Beirut | Beirut | Mazraa fonciere | 10310 | Basta Second Mixed Intermediate Public School | 33.88530718 | 35.5005407 |
| 27 | 30 | Beirut | Beirut | Mazraa fonciere | 10310 | Ras El Nabeh for Boys Secondary Public school | 33.88408715 | 35.5046986 |
| 28 | 31 | Beirut | Beirut | Mazraa fonciere | 10310 | Beirut Al Horj Secondary Public School for Boys | 33.88392615 | 35.5052886 |
| 29 | 32 | Beirut | Beirut | Mazraa fonciere | 10310 | El Basta First for Boys Public School | 33.88141322 | 35.50439569 |
| 30 | 34 | Beirut | Beirut | Mazraa fonciere | 10310 | Tariq Al Jadida First Intermediate Public School for Girls | 33.87349921 | 35.50237063 |
| 31 | 35 | Beirut | Beirut | Mazraa fonciere | 10310 | Tariq Al Jadida First Boys | 33.87019916 | 35.50217066 |
| 32 | 38 | Beirut | Beirut | Mazraa fonciere | 10310 | Jamiel El Rawass for Boys Secondary Public school | 33.87302515 | 35.5005016 |
| 33 | 40 | Beirut | Beirut | Mazraa fonciere | 10310 | Omar Farroukh for Girls Secondary Public School | 33.87299915 | 35.4953706 |
| 34 | 41 | Beirut | Beirut | Msaitbe fonciere | 10210 | Ibtihaj Qaddoura Mixed Intermediate | 33.86955322 | 35.49256831 |
| 35 | 42 | Beirut | Beirut | Mazraa fonciere | 10310 | Warda El Yazigi Mixed Public Kindergarten | 33.87119923 | 35.50477068 |
| 36 | 43 | Beirut | Beirut | Mazraa fonciere | 10310 | Tariq Al Jadida Third Public School for Girls | 33.8708992 | 35.50447066 |
| 37 | 44 | Beirut | Beirut | Mazraa fonciere | 10310 | Ras El Nabeh Second Public School for Girls | 33.88309218 | 35.50782968 |
| 38 | 45 | Beirut | Beirut | Achrafieh fonciere | 10650 | Ras El Nabeh First for Girls Public School | 33.88253722 | 35.51047465 |
| 39 | 47 | Beirut | Beirut | Mazraa fonciere | 10310 | Basta Boys Intermediate | 33.88177721 | 35.50620369 |
| 40 | 48 | Beirut | Beirut | Mazraa fonciere | 10310 | Tariq Aljadida Second for Girls | 33.87493215 | 35.5069636 |
| 41 | 49 | Beirut | Beirut | Aain el Mraisse fonciere | 10110 | Ain El Mraiseh Mixed Intermediate Public School (Doctor Sobhi Al Saleh PS) | 33.89979922 | 35.48857067 |
| 42 | 50 | Beirut | Beirut | Ras Beyrouth fonciere | 10150 | Ras Beirut First Mixed Public School (maybe Jaber Ahmad Al soba7) | 33.896252 | 35.47353 |
| 43 | 51 | Beirut | Beirut | Ras Beyrouth fonciere | 10150 | Al Manara Intermediate Public School for Girls | 33.894292 | 35.474953 |
| 44 | 52 | Beirut | Beirut | Ras Beyrouth fonciere | 10150 | Zahya Kaddoura for Girls Secondary Public School ( Ras Byrout) | 33.89438415 | 35.4746566 |
| 45 | 54 | Beirut | Beirut | Msaitbe fonciere | 10210 | Rami El Zarif Mixed Public School | 33.89219917 | 35.49207064 |
| 46 | 56 | Beirut | Beirut | Msaitbe fonciere | 10210 | Rene Mouawad Secondary Public School | 33.892099 | 35.487671 |
| 47 | 57 | Beirut | Beirut | Msaitbe fonciere | 10210 | Hasan Saab Mixed Secondary Public School | 33.89219915 | 35.4876706 |
| 48 | 58 | Beirut | Beirut | Ras Beyrouth fonciere | 10150 | Ras Beirut Second Mixed Public School French section | 33.88679921 | 35.47957061 |
| 49 | 60 | Beirut | Beirut | Msaitbe fonciere | 10210 | Rami El Zaydanieh for Girls Secondary School | 33.88819915 | 35.4901706 |
| 50 | 61 | Beirut | Beirut | Msaitbe fonciere | 10210 | Rami El Zaydanieh Kindergarten | 33.88631818 | 35.49286762 |
| 51 | 1406 | Beirut | Beirut | Mazraa fonciere | 10310 | Ras El Nabeh Second Mixed | 33.88408616 | 35.50591668 |
| 52 | 1477 | Beirut | Beirut | Mazraa fonciere | 10310 | Al Allama Abdullah Al Alayli Secondary | 33.87789915 | 35.4987706 |
| 53 | 1523 | Beirut | Beirut | Mazraa fonciere | 10310 | Omar El Zini Mixed Intermediate Public School | 33.87489918 | 35.49947068 |
| 54 | 1524 | Beirut | Beirut | Mazraa fonciere | 10310 | Emily Sursock Mixed Intermediate Public School | 33.86929918 | 35.49357062 |
| 55 | 1525 | Beirut | Beirut | Ras Beyrouth fonciere | 10150 | El Amir Shakib Irslan Mixed Intermediate ( Verdan ) | 33.8875992 | 35.47957069 |
| 56 | 1526 | Beirut | Beirut | Msaitbe fonciere | 10210 | Amr Al Ansi Mixed Public Kindergarten | 33.86941947 | 35.49262755 |
| 57 | 1527 | Beirut | Beirut | Mazraa fonciere | 10310 | Amin Bayham Mixed Elementary Public School | 33.86929918 | 35.49367063 |
| 58 | 1528 | Beirut | Beirut | Ras Beyrouth fonciere | 10150 | El Amir Shakib Irslan Mixed Secondary Public school | 33.89329915 | 35.4848706 |
| 59 | 1530 | Beirut | Beirut | Msaitbe fonciere | 10210 | Omar Hamad Mixed Elementary Public School | 33.86871515 | 35.4918036 |
| 60 | 1531 | Beirut | Beirut | Mazraa fonciere | 10310 | Amr Hamad Mixed Elementary Public School | 33.87505617 | 35.50067664 |
| 61 | 1532 | Beirut | Beirut | Mazraa fonciere | 10310 | Mohammed Shamel Mixed Elementary Public School | 33.87499919 | 35.49957065 |
| 62 | 1533 | Beirut | Beirut | Msaitbe fonciere | 10210 | Amr Fakhoury Mixed Elementary Public School | 33.86949918 | 35.49257061 |
| 63 | 1621 | Beirut | Beirut | El Ouzai | 21111 | Martyr adnan helbaoui public school_Ouzai | 33.837922 | 35.484318 |

*Figure 12 - Public Schools in Beirut provided by UNICEF*

*Figure 13 - 3D Model of municipal Beirut with public schools highlighted in red (prepared by: author)*

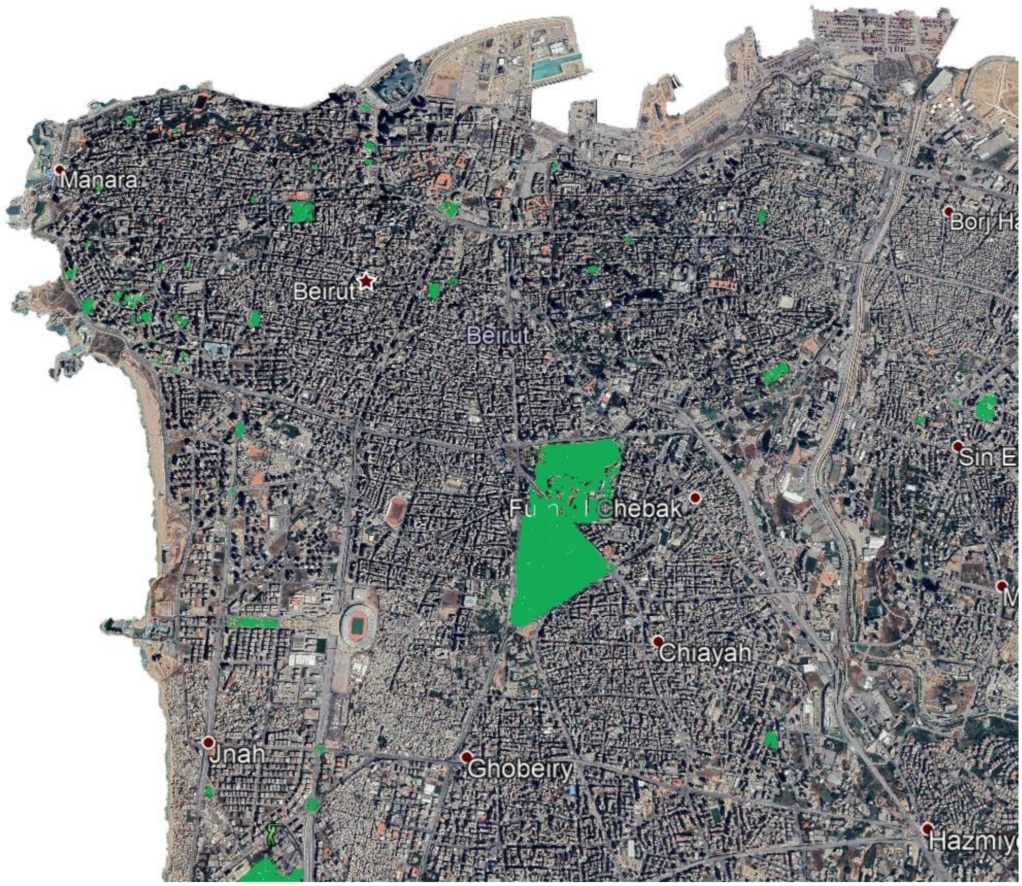



*Figure 14 - Left green spaces in Beirut 2020 (by: author)*

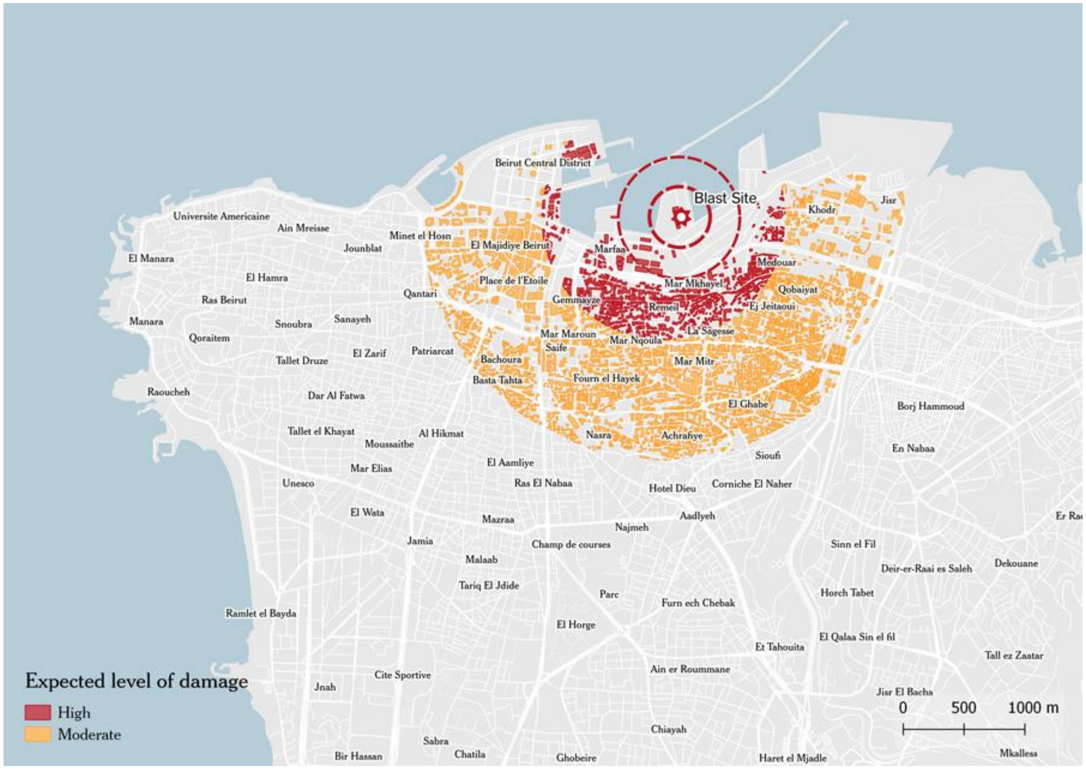



*Figure 15 - Beirut blast 4th of August, 2020 levels of damage (by: UNV)*

The analysis phase is based on the mentioned mapping following several steps. First, a process of overlapping of maps of figures 13 and 14 is conducted in order to define exactly the locations of schools according to the lack of green spaces in municipal Beirut and the impact of the 4th of August blast, which will be discussed as mentioned above in the limitations section of this Chapter. Second, further data are acquired as defined in Chapter 2, including the rooftop (architecture and design), the users (social aspect) and the role of this specific school in the community it is in (social values, history, urban ties), in addition to the building (type of construction, condition, rooftop area and height, materials), neighborhood and surroundings (shading buildings, exposure to sunlight) and the city (skyline, climate, urban heat island), in a way that each selected building is a model for the rest (this is based on an analysis of locations and building). All these collected data are added to the excel sheet mentioned above, which is provided by the UNICEF. Accordingly, only two schools are chosen to be a case study each, as explained in 3.2.

## 3.2. Case studies selections

### *3.2.1. Selection criteria: overlapping of maps*

As mentioned before, there are several criteria to choose which schools to be studied in this research. One approach is to overlap all the available data in order to filter out schools that could not serve this research. Therefore, overlapping the maps in figures 13, 14 and 15 produces the first step in analysis which is defining the schools' different locations according to the small existing green spaces in the city, and also the impacts left on the buildings from the $4^{th}$ of August blast of the Beirut port.

As explained before in Chapter 1, Beirut is a compact city with little green spaces. Figure 14 shows that there are few public parks that still exist today in the municipal Beirut, and they are considered the "lungs" of the city. However, these green spaces are far away from each other, dispersed around Beirut, therefore, for the sake of this study, schools that are chosen have to be far away from these green spaces in order to 'fill in the gap' in terms of green areas or patches around the city area.

Furthermore, as it will be explained later on in section 3.5., the study faced many limitations due to the current state Lebanon is in while this research is being conducted. One of these limitations is the Beirut blast that occurred on the $4^{th}$ of August, 2020, which resulted in destruction all over the city area on many levels. Therefore, damaged schools in the area of the blast cannot be chosen because this research relies on the school building being in its normal condition (not influenced by external forces such as the blast) and its ties to the community around it.

The base map is figure 13, showing the locations of the public schools in municipal Beirut. As shown in figure 16, figure 14 is overlapped on the base map, showcasing the locations of public schools in accordance to the left green spaces today in the city. While figure 17 shows the overlapping of figure 15 over the base map, defining the damaged public schools by Beirut blast on $4^{th}$ of August, 2020.

Figure 18 shows the overlapping of all three figures on the base map, filtering out the schools that are far away from the green spaces in the city, therefore need green spaces near them, and also the ones highly damaged from the $4^{th}$ of August blast, therefore cannot be chosen for this study.

In addition, this process of overlapping all these three maps shows the first step of filtering out schools, and paves the way for this study to have an initial understanding on which schools are to be chosen as study cases, according to their location in reference with the existing green spaces in municipal Beirut today, and also their affected status from the 4th of August blast. Therefore, figure 18 shows that the overlapping provided a result where six public schools are chosen as case studies; four in Achrafieh region and two in Ras Beirut area. They are highlighted in yellow in figure 18. Table 1 shows the selected six schools with their names and their coordinates.

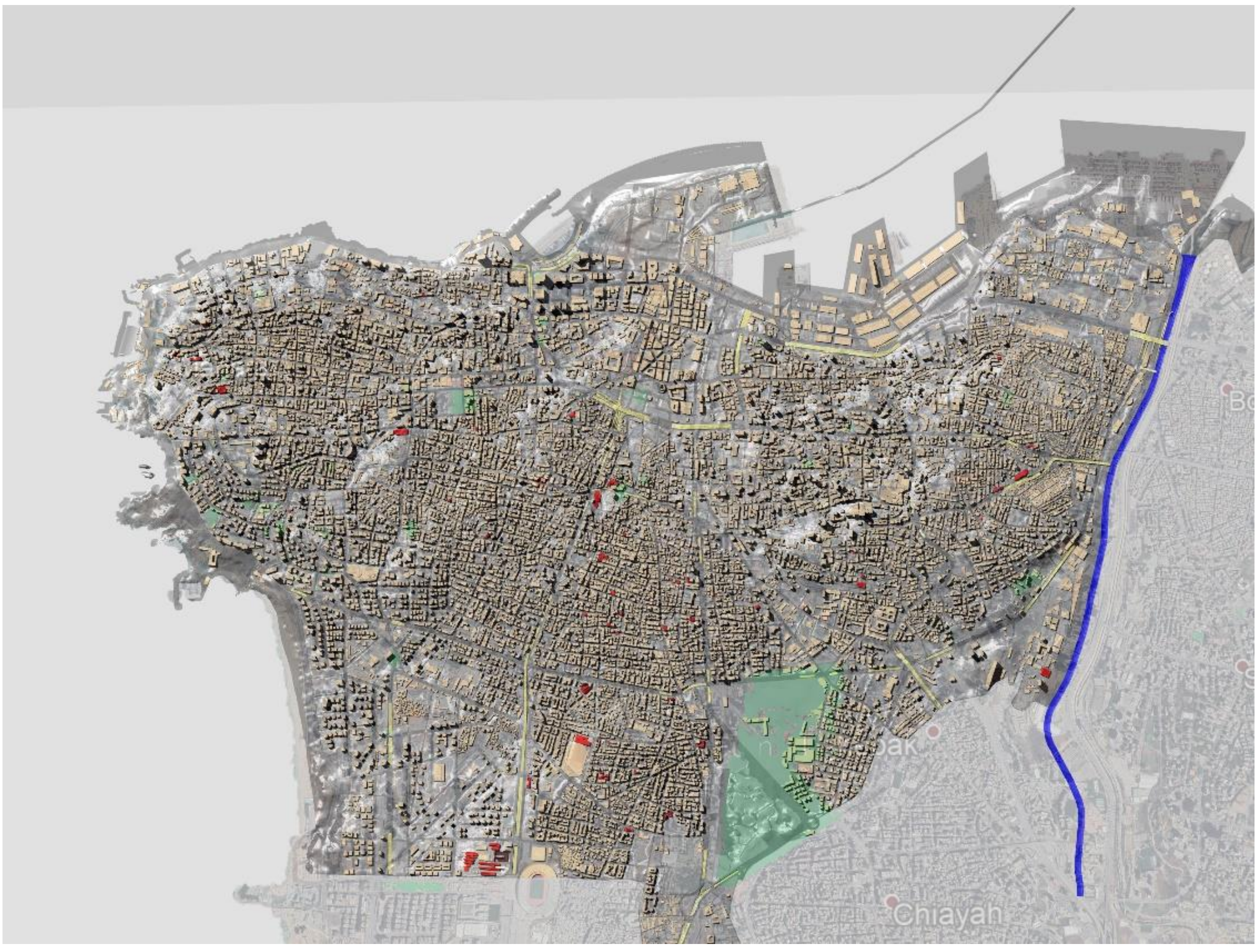


*Figure 16 - Overlapping #1: Public Schools and left green spaces in the city (prepared by: author)*

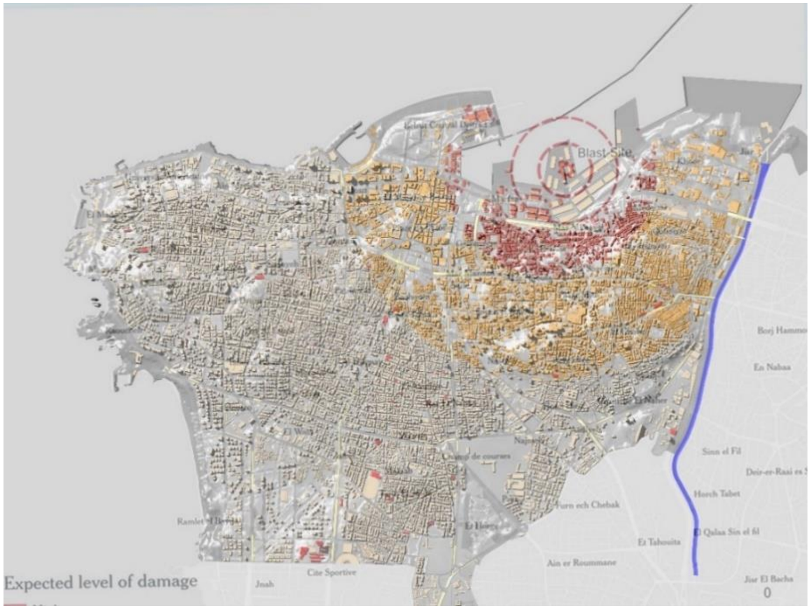



*Figure 17 - Overlapping #2: Public Schools vs. Beirut blast (prepared by: author)*

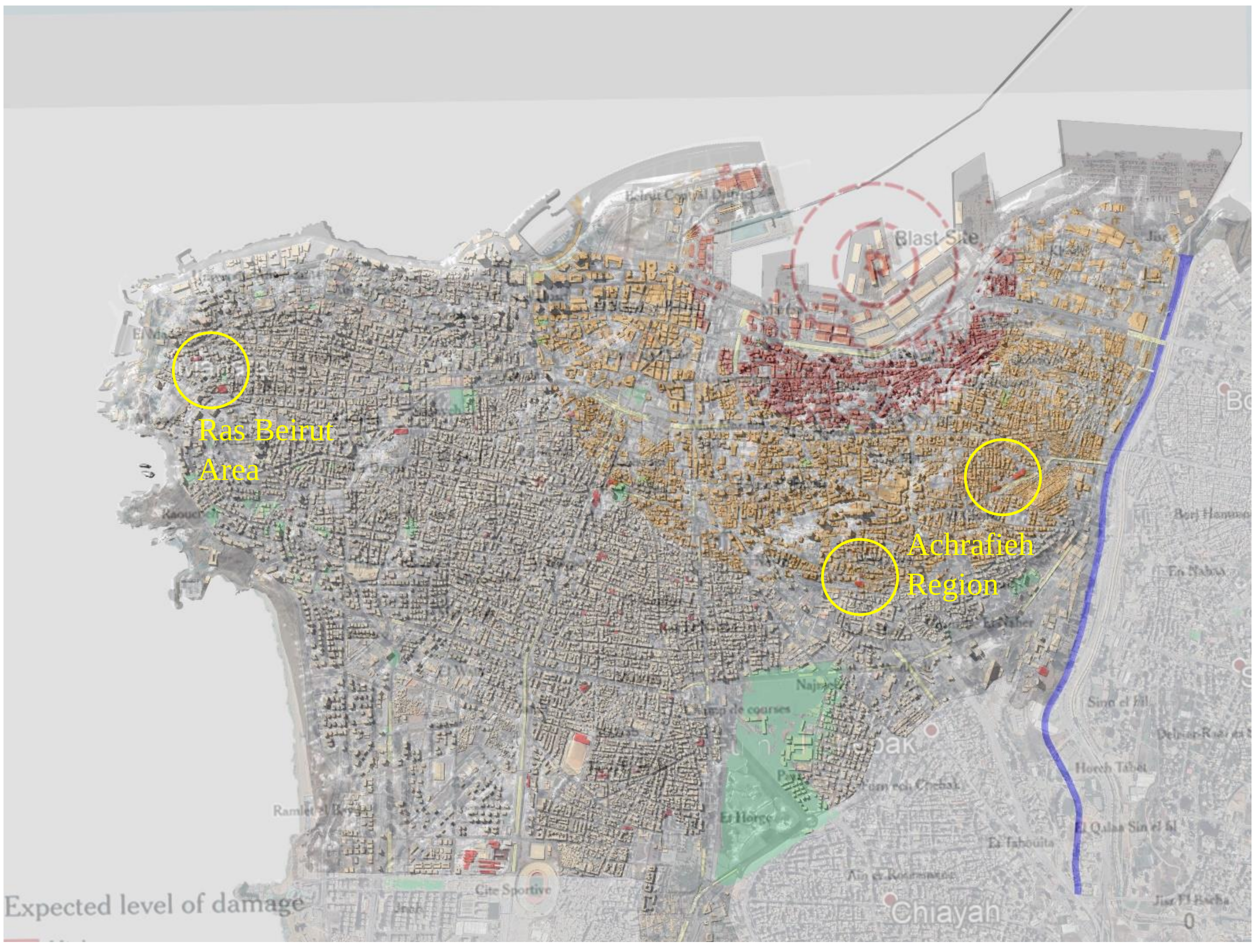



*Figure 18 - Overlapping #3: Six chosen public schools for study (prepared by: author)*

| | Governorate | Caza | Cadaster | CAS Code | School Name | Latitude | Longitude |
|---|---|---|---|---|---|---|---|
| **#5** | Beirut | Beirut | Achrafieh fonciere | 10650 | El Achrafieh First for Boys Secondary Public school | 33.88372915 | 35.51765456 |
| **#8** | Beirut | Beirut | Achrafieh fonciere | 10650 | Lor Mghayzil for Girls Secondary Public School | 33.88988215 | 35.5283736 |
| **#9** | Beirut | Beirut | Achrafieh fonciere | 10650 | El Achrafieh Mixed Intermediate Public school | 33.89145436 | 35.5287216 |
| **#10** | Beirut | Beirut | Achrafieh fonciere | 10650 | Karm El Zeitoun Mixed Intermediate Public School | 33.88896819 | 35.5264527 |
| **#50** | Beirut | Beirut | Ras Beirut fonciere | 10150 | Ras Beirut First Mixed Public School (maybe Jaber Ahmad Al soba7) | 33.896252 | 35.47353 |
| **#51** | Beirut | Beirut | Ras Beirut fonciere | 10150 | Al Manara Intermediate Public School for Girls | 33.89429218 | 35.47495261 |

*Table 1 - Selected Schools (extracted from: UNICEF, prepared by: author)*

### *3.2.2. Schools' data collection*

In order to locate the public schools, the data of the coordinates documented in the excel sheet provided by the UNICEF is used in this phase. In this excel sheet, as shown in figure 12, each school has a number, a cadaster which it belongs to, a CAS code, a name, and a latitude and a longitude which constitute its coordinates on google maps. All these categories are set within the excel sheet, which means that UNICEF has already done this part of data collecting. Based on these specifications provided, all public schools mentioned in this excel sheet are located on google earth using their coordinates. Using the 'project' tool on google earth, a project is created showing the locations of these public schools in municipal Beirut. By clicking on the following link, this project can be accessed and accordingly view the locating of the schools: https://earth.google.com/earth/d/1CKf6-hRLeBgZU-DjJz4mWrzY3VQs7-G3?usp=sharing .

Figure 19 also show this “project”, where the highlighted dropped pins are the public schools in municipal Beirut, as provided by the UNICEF.

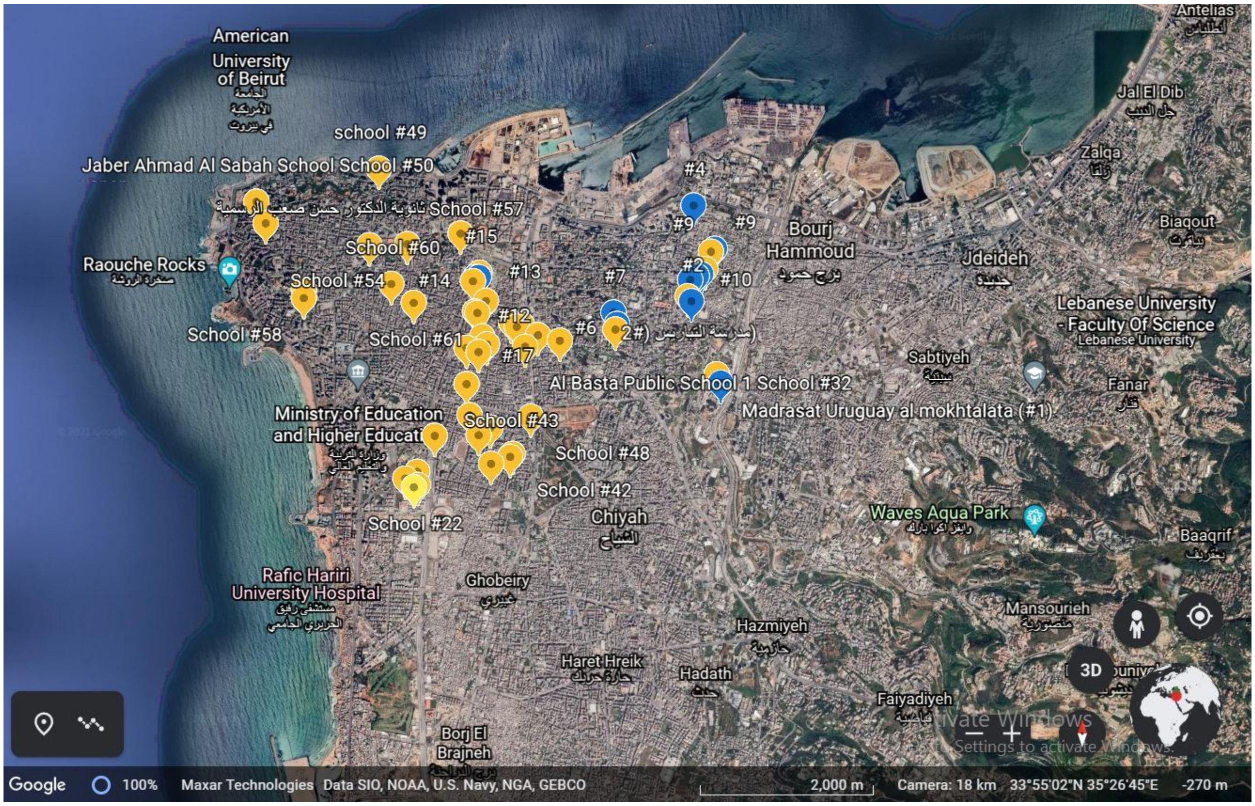


*Figure 19 - "Project" on google earth (prepared by: author)*

Each school is named according to its code number on the excel sheet, in order for the data to be all consistent.

Furthermore, using google earth, more categories are defined and added to the original excel sheet, providing more data collected. These categories include specifications of the school’s building, such as area of rooftop, zone or context in which the school building exists, type of rooftop, number of floors (including the ground floor), number of buildings, shape of the building, date of construction (was not used because no data was found except for only one school), operating status, and the building’s status from the 4th of August blast. (Figure 20)

| Area of Rooftop (m2) | Zone / category | Type of Rooftop | Number of Floors (+GF) | Nbr. Of Bldgs | Shape of Bldg | Date of Construction | Operating Status | Status from the Blast |
|---|---|---|---|---|---|---|---|---|
| 1500 | Next to high rise / Next to Highway | Flat | 5 | 1 | T-shape | | o | NA |
| 800 | On a hill | Flat | 4 | 1 | U-shape | | o | NA |
| 300 | Crowded Neighborhood | Flat | Tentative | 1 | Square | | o | NA |
| 1300 | Next to high rise | Flat | 4 | 1 | Rectangle | | o | NA |
| 250 | Next to high rise | Flat | Tentative | 1 | Square | | o | NA |
| 200 | Crowded Neighborhood | Flat | Tentative | 1 | Square | | o | NA |
| 1300 | On a hill | Flat | 4+ | 2 attached | Zigzag | | o | NA |
| 600 | Next to Highway | Flat | 3 | 1 | L-shape | | o | NA |
| 500 | Next to Highway | Flat | 3 | 2 attached | T-shape | | o | NA |
| 1000 | Crowded Neighborhood / Next to Religious | Flat | Tentative | 1 | U-shape | | o | NA |
| 450 | Crowded Neighborhood | Flat | Tentative | 1 | Square | | o | NA |
| | Next to Highway | Pitched Red Tile | Tentative | 1 | Rectangle | 1885 (Ottaman Period) | o | NA |
| 1200 | Next to Bridge | Flat | Tentative | 2 attached | U-shape | | o | NA |
| 500 | Next to University | Flat | Tentative | 1 | Zigzag | | o | NA |
| 400 | Crowded Neighborhood | Flat | Tentative | 2 attached | Rectangle | | o | NA |

*Figure 20 - Added categories to the original excel sheet (by: author)*

As shown in figure 20, the 'measure' tool on google earth is used in order to measure to the area of the building's rooftop, by drawing a line above the roof's outline and it is automatically calculated in m2 (square meter). The zone category defines where school's building is and its context in terms of neighborhood, surrounding buildings, near features (highway / bridge / high rise / religious facilities / sports facilities / other educational facilities). The type of rooftop is defined as 'flat' or 'pitched', as shown on google earth images, and then later double checked on site during the site visits, in order to facilitate the process of choosing schools with flat rooftops for they are compatible for this research according to the literature review in Chapter 2. The number of floors of the school's building is really important to be defined because the height of the building in comparison to that of its surrounding buildings can affect positively or negatively the type of vegetation to be used for the case study, due to the wind flow around the city context, which is a study that is conducted at a later stage after the first stage of filtering of schools. Furthermore, the ground floor is counted with the number of floors of the building, as shown in figure 20, where a specific number is written whenever the number of floors is double checked, a number with a plus sign is written whenever the number of floors are not shown fully, and the term 'tentative' is written whenever there is no sure answer about how many floors does this specific building have. Number of buildings and shape of buildings are the categories that define the school's shape. Some schools have two or more buildings that are either separated or attached, also some schools are of different shapes (T-shape / U-shape / L-shape / Square / Rectangle / Zigzag). Date of construction, as stated before, is a category that was not used due to the fact that no data was found on all schools except for only one, which will be discussed later in the analysis

Chapter. The operating status shows that all public schools present in municipal Beirut are still operating (the term 'O' is written as abbreviation) normally. Finally, the status from the blast show if the school's building is affected by Beirut's port blast (the term 'NA' is written as abbreviation for Not Affected).

In order to start the process of filtering out in a proper scientific manner, this approach is chosen to be conducted in this research. Therefore, all these data are collected on the public schools, then they are classified and documented in an excel sheet.

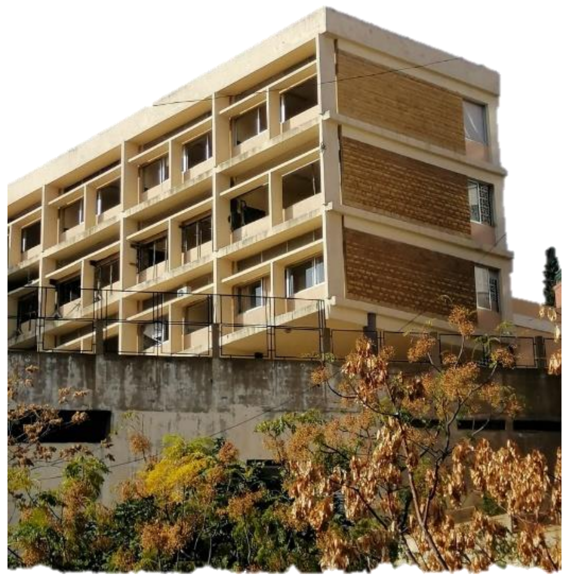
## 3.3. Empirical work

The empirical work for this study includes going on site visits to capture photos of how the community is interacting with the school, which is an important aspect that will be discussed and explained in the sub-section of parameters in this chapter. In addition, as it will be explained in section 3.5., this study faced limitations due to the spread of COVID-19 at the time of the conduction of the research, therefore detailed interviews and long questionnaires are not conducted due to a lockdown in the country, which lead to the closing of schools and online learning. Therefore, the empirical work only involves site visits and collecting data online whenever it is possible.

However, two brief interviews have been conducted. Ms. Ghada Azar, the secretary at one of the public schools chosen for this study, is the first interviewee. During the interview, various questions were asked about the name of the school, the year of construction of the building, the type of program offered, the primary foreign language used, along with some characteristics about the building itself such as the number of floors, the number of class rooms, and the current usage of the rooftop. The interview resulted in some brief data provided by Ms. Azar, and it is explained all in details in Chapter 4 in sub-section 4.4.4.c. Moreover, the second interviewee is Mr. Jean Pierre Succar, a civil engineer with a site experience of more than ten years. Mr. succar was asked some questions about the characteristics of the structure of the buildings in question, and later suggested some materials to be used in the design proposal. The interview resulted in some brief data provided by Mr. Succar, and it is explained all in details in Chapter 4 in sub-section 4.4.3.e.

The site visit is conducted and figure 21 shows the six selected schools in the first process of elimination, as mentioned above in section 3.2.1. (showing their location, surroundings, context, etc.). The schools are being described in their respective order of Table 1.

School #5



School #8


*Figure 21 - Photos of schools chosen (Captured by: author)*

## 3.4. Analysis Tools

Several software are used in studying the data collected such as Google Maps and cadastral maps using Rhino for 3D models, Photoshop for overlapping the maps and creating visuals, and Autodesk CFD[4] (software for measuring the wind flow in a certain region in order to determine which vegetables will be grown and how best to orient the proposed design later on).

## 3.5. Limitations

One of the limitations of this research is the Beirut blast that occurred on August 4th, 2020 in the port of Beirut. The occurrence of this blast resulted in a delay in this study and an absence of data. Going back to figure 15, the map shows the location of the blast and the level of damage it left on the city of Beirut. (UNV, 2020)

In addition, this study faced limitations due to the spread of COVID-19 at the time of the conduction of the research, therefore thorough interviews and questionnaires are not conducted due to a lockdown in the country, which lead to the closing of schools and online learning.

More limitations are that there is no access to data about all the existing schools in municipal Beirut, private and public, showing all their locations. Only data about the locations of public schools was provided by UNICEF, therefore, the research is based solely on the rooftops of public schools in municipal Beirut.

Furthermore, due to the current state in the world and in Lebanon specifically, this research faced a lot of limitations towards the end. The empirical work in that case was disrupted many times, the possibility of not being able to access a certain location or school, interviews were delayed or even cancelled, and surveys were not conducted at all. In addition, a potential case study does not take place. Therefore, this study is solely based on research online in addition to site visits and interactions with a limited number of people to provide more information and data either through small questionnaires or brief interviews.

[4] CFD: Computational Fluid Dynamics

## 3.6. Parameters

In order to conduct this study, thorough research is done on more literature to identify different parameters that define how the work is done from analysis to understanding the results. Therefore, this is based on more research done previously. These parameters are grouped into themes or categories and are explained in the following five sub-sections, each one explaining a category.

### *3.6.1. Values of having green spaces as public spaces in the city*

Urban green spaces take up many roles, and are designed and built for a variety of purposes such as social, recreational and cultural purposes. In addition of course to their environmental benefits, they also have economic benefits where the property value increases due to their aesthetic characteristics functionality and rareness in the city (Lee et al., 2015). Additionally, green spaces have many values on many levels such as social value, comfort value, public interaction and mental health. Having a green space nearby residences, that is easily accessed by various inhabitants such as a rooftop of the building, can provide a relaxing space for them to decompress from the city's chaos (Someh et al., 2014). Moreover, doctors are encouraging more and more urban dwellers to spend more time in green spaces outdoors, which would benefit their health in fighting dementia suffers, help decrease obesity risks and help with mental health issues. (Hardman et al., 2019)

As for the main three benefits of the green spaces in the city, in terms of sustainability, they are based on the three pillars: environment, economy and sociality. Environmental values include a natural treatment of the atmosphere (polluted air) through the process of photosynthesis, an urban climate moderation through shade effect and humidity, and noise mitigation. The economic benefits involve the attractiveness of urban centers, which increases the investment in urban properties, which in turn increases the value of housing in the city. While the social values of such spaces comprise, but are not limited to, increase in social inclusion where everyone is encouraged to participate with no regards to sex, age and status, promotion of urban health by encouraging a more active lifestyle, and a respond to human needs for recreation and leisure (Marinescu, 2011). Here comes the role of the school in this matter, being a place that offers socio-educational activities with strong links to families, a school in an urban context comprises of various students from all over the area, which would spread the educational experience about agriculture and the importance of greenery in a city better among citizens and make sure everyone is included in the process (Nadal et al., 2018). (Figure 22)


*Figure 22 - Green Space and Health (Prepared by: author)*

### *3.6.2. Perception of nature within the urban context*

Green rooftops in the city context is often times considered as an escape from the city's monochromatic structures. They add a little life to the neighborhood and community visually and aesthetically (Bell, 2019). In addition, green rooftops connect visually the urban areas with the sub-urban ones by creating this link and a comfortable environment for the urban dwellers. (Giannopoulou et al., 2019)

Many authors argue that green areas in the city help in decreasing the negative effect of urbanization on both the population and the environment, where they "act as a second living space for residents in an increasingly dense city" (Niemelä et al., 2010).

Moreover, cities and nature are directly linked; the increase in dense urbanization leads to a decrease in green spaces in the city, which effects negatively the biodiversity by modifying the existing fauna and flora in urban areas (Parva et al., 2017). Therefore, increasing the green spaces in the city, or adding them if they no longer exist, can help in reversing the negative effect of increased urban densification on the environment.

Moreover, one would ask why is the need to have a green rooftop on top of a school building and what is the added value? As Selzer argues in her thesis in 2019, "children growing up in cities have fewer opportunities to interact with natural settings. Their perception of the natural world has been defined by their experiences with urban nature, the green spaces that are a part of the built environment. This lack of exposure to the natural environment often contributes to feelings of removal from environmental issues, which are prevalent among urban youth." (Selzer, 2019, p. 5).

Schools, being the number one place where children interact and learn, can offer this opportunity to them where they are introduced to the natural environment and are able to experience it firsthand.

(Figure 23)


*Figure 23 - Nature in Urban Context (Prepared by: author)*

### *3.6.3. Accessibility of public to the green rooftop*

One of the main criteria of a public space is that it should be accessible at all times by everyone with no exception and no charge of money, therefore, it is important that the green rooftop is treated as such (Payne, 2017), in order to maximize the usage of it. Yet, “an important consideration in equity issues is who owns this green roof and who benefits from it” (Calvin, 2016). Many studies show that people tend more to set a green roof on top of a residential building, resulting that the roof is considered more as a private space rather than public, because public spaces need maintenance and management constantly (Rahman et al., 2013). Therefore, a green rooftop in a school building (institutional building) is considered a solution to both these issues, in terms of who owns this space and who manages and maintains it.

Moreover, important issues need to be considered which are safety, such as the need of having a rail on the edges of the rooftop (if it is not available) in order to protect from falling, in addition to the access to and from the roof space, and also the load bearing capacity and management of the space. (Livingroofs, n.d.) (Figure 23)

*3.6.4. Proportion of building area to green spaces*

The area of the green space introduced to the existing rooftop is according to the area of the roof. Therefore, the larger the building area, the larger the green area is. (Livingroofs, n.d.)

In order to transform an existing rooftop into a green one, the rooftop state needs to be defined in terms of -and not specific to- area, construction type, orientation, roof tilt angle, location, shading, as well as other existing uses, such as air conditioning and heating installations, water tanks, elevator shafts, roof terraces, or penthouses (Ordonez et al., 2010). Then, the usable area of the roof and the need of a greenhouse and its type of either extensive or intensive are studied thoroughly (Benis et al., 2018).

School buildings in cities in general, and in Beirut in particular, are of large area with large open areas around them that serve as playgrounds most of the time, as will be seen in Chapter 4, the analysis part of this study. Therefore, the need of having a larger rooftop that leads a larger green space is met here.

*3.6.5. Activities to be held in a green rooftop*

Green rooftop is considered a public space, as explained before, therefore, it may include many different activities to attract more users and create a comfortable space and environment for them. Activities such as gardening, a playground for kids, an outdoor gym, a public park including urban furniture (benches, swings, …), and any type of sports are an example of how a green rooftop can be used and benefited from as a public space in the city (Lenhart, 2017). Marinescu (2011) divides these activities into three main categories; general activities such as playgrounds and trails, sports activities such as tennis, soccer, basketball and football, and finally special activities such as gardening, concerts and other cultural events (Marinescu, 2011).

In addition, "the role of the community greatly influences the success of the green rooftop in achieving energy efficiency and sustainable development, hence, the role of the community could be managed through controlling the communal activities" ( Hardiman et al., 2020, p. 3)

As mentioned before in 3.6.2, schools are a place that offers endless opportunities to add to one's knowledge, and having a green rooftop in the school building can do just that, especially for children living in urban areas who are not exposed to wild natural environment (Selzer, 2019). Schools play an important role in developing the awareness of students and their families about urban agriculture, food safety and importance of green spaces within the urban context, through educational activities related to these aspects in a setting that encourages participation such as a green roof (Nadal et al., 2018). (Figure 24)


*Figure 24 - Activities in Green Rooftop (Prepared by: author)*

## 3.7. Synthesis

Since the process of collecting these data sets involves analyzing documents and comparing numbers to numbers, it is a quantitative method. Also, since it involves interviewing people and coding their behavior, it is also considered a qualitative method. Therefore, the research process is a mixed methods one.

In addition, a rational approach has been used that doesn't allow the writer to generalize the results that are verified under specific conditions.

The purpose of this research is to arrive at a conclusion that would answer the research questions stated in Chapter 1, where it defines how an existing rooftop can be transformed to be a sustainable one while focusing on the importance of schools and their role in the community and the city of Beirut.

# **Chapter 4-** Analysis and Discussion

This chapter introduces the analysis process used for this study, and the discussion about the results found. In order to better understand the process of analysis and the results found, this chapter is composed of five sections, with sub-sections, each showcasing a step of the analysis and the results arrived to in each step. The following five sections describe the steps in analysis; reading the results which is a descriptive process, analyzing the results which is a synthesizing process, and validating the results internally and externally from other literature reviews, in order to ensure that the results are significant. The first section describes the process of the first short-listing of public schools in municipal Beirut, and how six schools are selected as an initial filtering, leading to a more detailed and classified short-listing of the schools, based on different categories such as the area of the rooftop, the surrounding buildings, and the shape of the building, which is described in sub-section 4.1.2. The second section shows a more thorough study on the selected schools in the previous section, leading to another process of short-listing, in order to choose finally two schools to act as models for the others. While the third section discusses the CFD analysis and results used in this study on the two selected schools, section 4.4 presents the two different proposals of ‘green’ rooftops on each public school, serving as pilot projects for the other public schools in municipal Beirut and Lebanon. Finally, a conclusion summarizes this chapter and introduces the next one.

In addition, since no data was allowed to be accessed from the Municipality of Beirut in terms of cadastral maps of the area where the schools are highlighted, maps had to be redrawn and more information about schools had to be researched more from different source.

Database from the UNICEF was accessed and it provided this research with an excel sheet showing only the existing public schools in municipal Beirut, their names and their coordinates on Google Maps (Figure 19).

Using google maps, I was able to extract top views of municipal Beirut, and therefore base maps for this research, showcasing first the existing green areas in the city today, to compare it with the green areas that used to exist in the old days in the same area, and also the different locations of public schools of municipal Beirut.

In order for the research to be more accurate, since most of the data are not accessed from the main sources and I had to therefore create the data from scratch, different AutoCAD and Rhino files of

Beirut maps were downloaded from the internet and were compared and overlapped in order to create the most accurate map of Beirut to be adequate for the conduction of this research.

## 4.1. First short-listing of public schools: general analysis

The first step of filtering out the public schools in municipal Beirut, in order to choose two schools to conduct this research, is by studying the public schools in the area first in general. This section explains how this process is conducted, and the results obtained from it.

As explained before in Chapter 3, there are several criteria in order to choose which schools to be studied in this research. The first approach is to overlap all the available data in order to filter out schools that could not serve this research.

Figure 13 shows a 3D model of municipal Beirut drawn in Rhino, which is a 3D modeling software, in 2019. The model shows the area of municipal Beirut with its topography, buildings and streets. Highlighted in red in this figure, are the public schools in municipal Beirut that are functioning today.

Figure 14 shows the map extracted from Google Maps showcasing information about the left green spaces in Beirut in 2020.

Figure 15 shows the approximate impact of Beirut blast that occurred in August 4$^{th}$, 2020, which is discussed furthermore in the previous Chapter, the Limitations, section 3.5. This map is provided by the UNV, in order to define approximately the impacts of the blast on the city area and the levels of damage it left on the buildings and the city overall.

Therefore, overlapping the maps in figures 13, 14 and 15 produces the first step in analysis which is defining the schools' different locations according to the small existing green spaces in the city, and also the impacts left on the buildings from the 4$^{th}$ of August blast of the Beirut port.

As explained before in Chapter 1, the city of Beirut is compacted with buildings. Figure 14 shows that there are few public parks or green patches that still exist today in the municipal Beirut, and they are considered the "lungs" of the city. However, these green spaces are far away from each other, dispersed around Beirut, therefore, for the sake of this study, schools that are chosen have to be far away from these green spaces in order to 'fill in the gap' in terms of green areas or patches around the city area.

Furthermore, as explained in Chapter 3, section 3.5., the study faced many limitations due to the current state Lebanon is in while this research is being conducted. One of these limitations is the Beirut blast that occurred on the 4th of August, 2020, which resulted in several levels of destruction all over the city area. Therefore, damaged schools in the area of the blast cannot be chosen because this research relies on the school building being in its normal condition (not influenced by external forces such as the blast) and its ties to the community around it.

The base map is figure 13, showing the locations of the public schools in municipal Beirut. As shown in figure 16, figure 14 is overlapped on the base map, showcasing the locations of public schools in accordance to the left green spaces today in the city. While figure 17 shows the overlapping of figure 15 over the base map, defining the damaged public schools by Beirut blast on 4th of August, 2020.

Figure 18 shows the overlapping of all three figures on the base map, filtering out the schools that are far away from the green spaces in the city, therefore need green spaces near them, and also the ones highly damaged from the 4th of August blast, therefore cannot be chosen for this study.

In addition, this process of overlapping all these three maps shows the first step of filtering out schools, and paves the way for this study to have an initial understanding on which schools are to be chosen as study cases, and in which different areas of the city, according to their location in reference with the existing green spaces in municipal Beirut today, and also their affected status from the 4th of August blast. Therefore, figure 18 shows that the overlapping provided a result where six public schools are chosen as case studies; four in Achrafieh region and two in Ras Beirut area. They are highlighted in yellow in figure 18. Table 1 shows the selected six schools with their names and their coordinates.

As shown in Chapter 3, a small empirical work was conducted. It consisted of a brief site visit to the six schools chosen in this first step of the research process. The visit is documented by photos of the schools, showing their location in comparison to their immediate surroundings, the interaction with the roads, the access to them, and the human interactions around each building school. Figure 21 shows these six visited schools. Schools number five, eight, nine and ten are located in Ashrafieh area, while schools number fifty and fifty one are located in Ras Beirut. Table 1 shows further information about these six schools. These information are extracted from the excel sheet provided by the UNICEF, as mentioned before in the previous chapter. To note that the numbering of these schools is kept the same as the provided excel sheet, to respect the data and its source. In addition, the numbering is also the same throughout all this research, so whenever a certain public school is mentioned along this research, it is referred to its original code or number on the excel sheet, which is also included in the Appendix of this research.

## 4.2. Second short-listing of public schools: thorough analysis

### *4.2.1. Creating a "project" on Google Earth, collecting data on the public schools in municipal Beirut and documenting them properly*

In order to locate the public schools, the excel sheet provided by the UNICEF is used in this phase, which is the second phase of the analysis process. In this excel sheet, as shown in figure 12, each school has a number, a cadaster which it belongs to, a CAS code, a name, and a latitude and a longitude which constitute its coordinates on google maps. All these categories are set within the excel sheet, which means that UNICEF has already done this part of data collecting. Based on these specifications provided, all public schools mentioned in this excel sheet are located on google earth using their coordinates. Using the 'project' tool on google earth (figure 25), a project is created to show the locations of these public schools in municipal Beirut. By clicking on the following link, this project can be accessed and accordingly view the locating of the schools: https://earth.google.com/earth/d/1CKf6-hRLeBgZU-DjJz4mWrzY3VQs7-G3?usp=sharing .

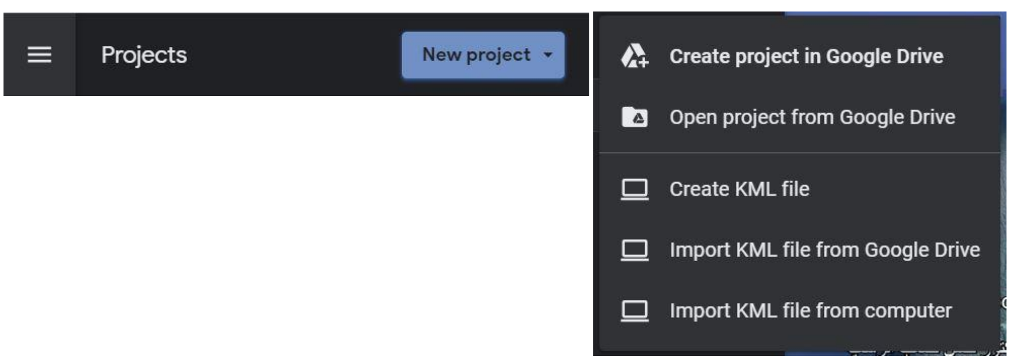



*Figure 25 - How to create a new project on Google Earth (Prepared by: author)*

After a new project is created, it is named and saved under this name, and it is shared with everyone who has a link to it. Then, you search for the coordinates of each school that are available on the excel sheet data. A pin appears showing the exact location provided by these coordinates, the “dropping pin” tool is used here in order to save this location in the “project” and name it; in this research process, I named each location according to its school name respectively, along with the same numbering or code from the excel sheet, in order to be consistent. Figures 26 and 27 show this process in steps.

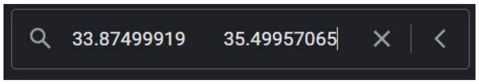



*Figure 26 - Copy and paste the coordinates into the Search engine (Prepared by: author)*


*Figure 27 - Saving the found location to the "project" (Prepared by: author)*

As shown in figure 27, the red pin is the searched location, while the yellow pin is the saved location. So whenever you save a location, the pin in it turns from red to yellow, and it is now saved into the project.

Figure 28 also shows this “project”, where all the highlighted dropped pins are the public schools in municipal Beirut, as provided by the UNICEF.

*Figure 28 - All the saved pins in the "project", showing the locations of all public schools in municipal Beirut (Prepared by: author)*

As shown in figure 29, the 'measure' tool on google earth is used in order to measure to the area of the building's rooftop, by drawing a line above the roof's outline and it is automatically calculated in square meter (m2).

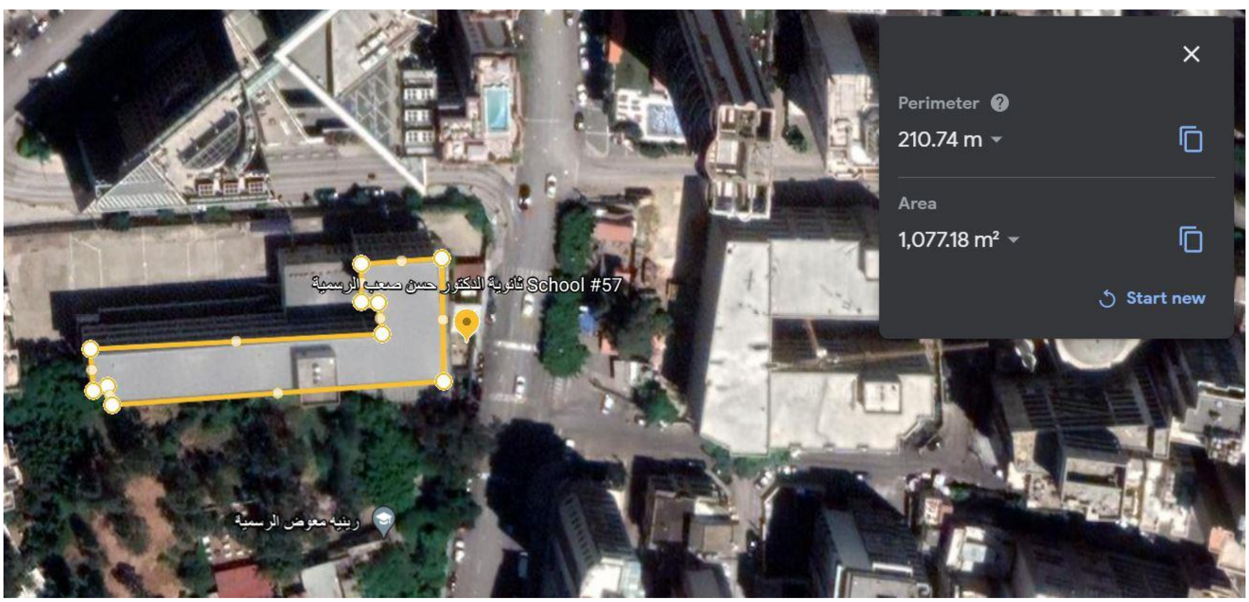


*Figure 29 - Measure tool on google earth to measure the area of the rooftop of a school in square meter (Prepared by: author)*

Each school is named according to its code number on the excel sheet, in order for the data to be all consistent. (Figure 30) (Table 2)

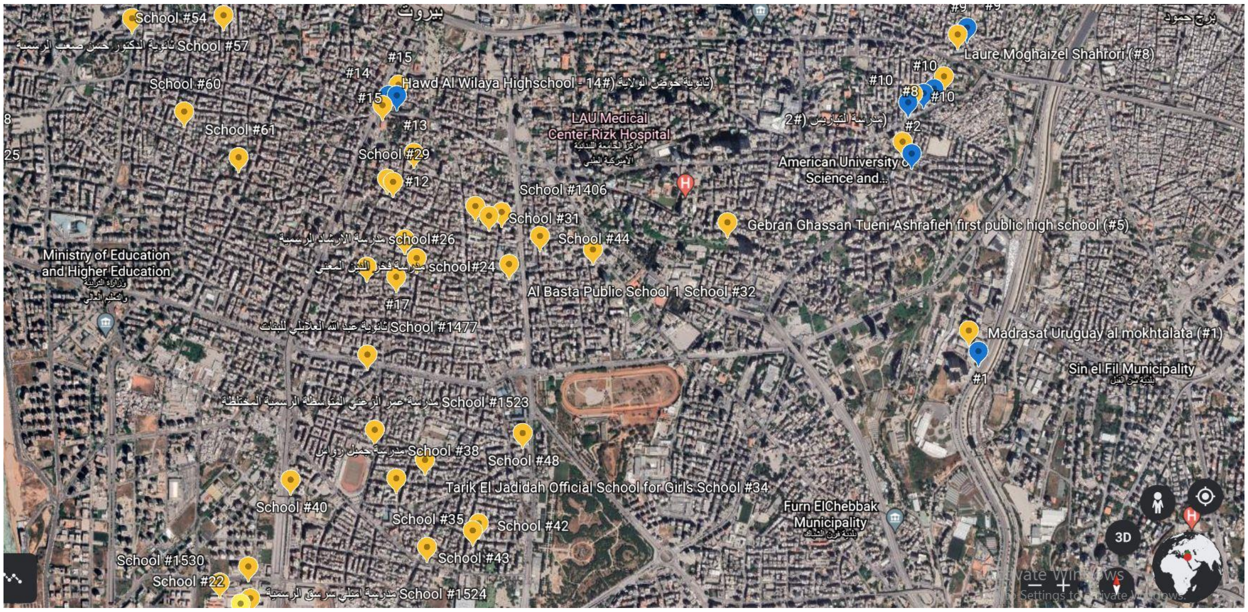


*Figure 30 - Numbering or coding of all public schools in municipal Beirut (Prepared by: author)*

In addition to the code or numbering of the school and the name of the school, table 2 shows also the cadaster in which each school is located. The cadasters are different regions that are form municipal Beirut, and are under the control of municipality of Beirut.

| Code / Numbering | Cadaster | Name of School |
|---|---|---|
| **1** | Achrafieh fonciere | Uruguay First Achrafieh Public School for Boys |
| **2** | Achrafieh fonciere | El Tabaris El Namozajia for Girls Public School |
| **4** | Rmeil fonciere | Achrafieh Third Mixed Intermediate Public School |
| **5** | Achrafieh fonciere | El Achrafieh First for Boys Secondary Public school |
| **6** | Achrafieh fonciere | El Achrafieh Second Secondary Public School |
| **7** | Achrafieh fonciere | Salma El Sayegh Public School for Girls |
| **8** | Achrafieh fonciere | Lor Mghayzil for Girls Secondary Public School |
| **9** | Achrafieh fonciere | El Achrafieh Mixed Intermediate Public school |
| **10** | Achrafieh fonciere | Karm El Zeitoun Mixed Intermediate Public School |
| **12** | Mazraa fonciere | Beirut Alaliya Girls Intermediate |
| **13** | Bachoura fonciere | Al Mousaitbeh Public School for Boys |
| **14** | Bachoura fonciere | Houd Alwilaya First Mixed |

| | | |
|---|---|---|
| **15** | Bachoura fonciere | El Mostakbal Mixed Public School |
| **16** | Zqaq el-Blat fonciere | Zoqaq AlBlat Mixed |
| **17** | Mazraa fonciere | For Girls Second Public School |
| **19** | Bachoura fonciere | Mufti Shaheed Hasan Khaled Secondary |
| **20** | Mazraa fonciere | Burj Abi Haidar Mixed Public Kindergarten |
| **21** | Msaitbe fonciere | Wata Al Mousaitbeh Mixed Public School |
| **22** | Msaitbe fonciere | Zahia Salman Secondary Public School (formerly Wata El Msaytbeh) |
| **23** | Msaitbe fonciere | Namouzajiya Mixed Public School |
| **24** | Mazraa fonciere | Fakhreddine El Maani Secondary Public School for Girls |
| **25** | Mazraa fonciere | King Saoud Girls Intermediate |
| **26** | Mazraa fonciere | Al Irshad Public School for Girls |
| **27** | Mazraa fonciere | Mazraa First Boys Intermediate |
| **29** | Mazraa fonciere | Basta Second Mixed Intermediate Public School |
| **30** | Mazraa fonciere | Ras El Nabeh for Boys Secondary Public school |
| **31** | Mazraa fonciere | Beirut Al Horj Secondary Public School for Boys |
| **32** | Mazraa fonciere | El Basta First for Boys Public School |
| **34** | Mazraa fonciere | Tariq Al Jadida First Intermediate Public School for Girls |
| **35** | Mazraa fonciere | Tariq Al Jadida First Boys |
| **38** | Mazraa fonciere | Jamiel El Rawass for Boys Secondary Public school |
| **40** | Mazraa fonciere | Omar Farroukh for Girls Secondary Public School |
| **41** | Msaitbe fonciere | Ibtihaj Qaddoura Mixed Intermediate |
| **42** | Mazraa fonciere | Warda El Yazigi Mixed Public Kindergarten |
| **43** | Mazraa fonciere | Tariq Al Jadida Third Public School for Girls |
| **44** | Mazraa fonciere | Ras El Nabeh Second Public School for Girls |
| **45** | Achrafieh fonciere | Ras El Nabeh First for Girls Public School |
| **47** | Mazraa fonciere | Basta Boys Intermediate |
| **48** | Mazraa fonciere | Tariq Aljadida Second for Girls |
| **49** | Aain el-Mraisse fonciere | Ain El Mraiseh Mixed Intermediate Public School (Doctor Sobhi Al Saleh PS) |
| **50** | Ras Beyrouth fonciere | Ras Beirut First Mixed Public School (maybe Jaber Ahmad Al soba7) |
| **51** | Ras Beyrouth fonciere | Al Manara Intermediate Public School for Girls |
| **52** | Ras Beyrouth fonciere | Zahya Kaddoura for Girls Secondary Public School ( Ras Byrout) |
| **54** | Msaitbe fonciere | Raml El Zarif Mixed Public School |
| **56** | Msaitbe fonciere | Rene Mouawad Secondary Public School |
| **57** | Msaitbe fonciere | Hasan Saab Mixed Secondary Public School |

| | | |
|---|---|---|
| **58** | Ras Beyrouth fonciere | Ras Beirut Second Mixed Public School French section |
| **60** | Msaitbe fonciere | Raml El Zaydanieh for Girls Secondary School |
| **61** | Msaitbe fonciere | Raml El Zaydanieh Kindergarten |
| **1406** | Mazraa fonciere | Ras El Nabeh Second Mixed |
| **1477** | Mazraa fonciere | Al Allama Abdullah Al Alayli Secondary |
| **1523** | Mazraa fonciere | Omar El Zini Mixed Intermediate Public School |
| **1524** | Mazraa fonciere | Emily Sursock Mixed Intermediate Public School |
| **1525** | Ras Beyrouth fonciere | El Amir Shakib Irslan Mixed Intermediate ( Verdan ) |
| **1526** | Msaitbe fonciere | Amr Al Ansi Mixed Public Kindergarten |
| **1527** | Mazraa fonciere | Amin Bayham Mixed Elementary Public School |
| **1528** | Ras Beyrouth fonciere | El Amir Shakib Irslan Mixed Secondary Public school |
| **1530** | Msaitbe fonciere | Omar Hamad Mixed Elementary Public School |
| **1531** | Mazraa fonciere | Amr Hamad Mixed Elementary Public School |
| **1532** | Mazraa fonciere | Mohammed Shamel Mixed Elementary Public School |
| **1533** | Msaitbe fonciere | Amr Fakhoury Mixed Elementary Public School |
| **1621** | El Ouzai | Martyr adnan helbaoui public school_Ouzai |

*Table 2 - Coding, Cadaster and Name of School (Data provided by: UNICEF, Prepared by: author)*

Furthermore, using google earth, more categories are defined and added to the original excel sheet, providing more data collected. These categories include specifications of the school's building, such as area of rooftop, zone or context in which the school building exists, type of rooftop, number of floors (including the ground floor), number of buildings, shape of the building, date of construction (was not used because no data was found except for only one school), operating status, and the building's status from the 4$^{th}$ of August blast. (Table 3)

| **Area of rooftop (m2)** | **Data extracted from Google Earth, using the "measure" tool as explained previously in this section.** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Zone / Category** | Next to High Rise | Next to Highway | On a Hill | Crowded Neighborhood | Next to Religious Facilities | Next to Educational Facilities | |
| **Type of Rooftop** | Flat | | | Pitched with Red tile | | | |
| **Number of Floors (+GF)** | Defined Number (x) | | Defined Number plus (x+) | | Not Known (Tentative) | | |
| **Number of Buildings** | One | Two attached | | Three attached | | Four attached | |
| **Shape of Building** | Square | Rectangle | T-shape | L-shape | U-shape | O-shape | Zigzag |
| **Date of Construction** | NOT FOUND (except for only one school; dating back to the Ottoman Period in 1885, however its roof is pitched with red tile, therefore it is not used in this research) | | | | | | |
| **Operating Status** | Operating normally (O) | | | | | | |
| **Status from the Blast** | Affected (A) | | | Not Affected (NA) | | | |

*Table 3 - Added categories to the data (Prepared by: author)*

The zone category defines where school's building is and its context in terms of neighborhood, surrounding buildings, near features (highway / bridge / high rise / religious facilities / sports facilities / other educational facilities). The type of rooftop is defined as 'flat' or 'pitched', as shown on google earth images, in order to facilitate the process of choosing schools with flat rooftops for they are compatible for this research according to the literature review in Chapter 2. The number of floors of the school's building is really important to be defined because the height of the building, in comparison to that of its surrounding buildings, can affect positively or negatively the type of vegetation to be used for the case study, due to the wind flow around the city context, which is a study that is conducted at a later stage after the first stage of filtering of schools. Furthermore, the ground floor is counted with the number of floors of the building, as shown in table 3, where a specific number is written whenever the number of floors is made sure of, a number with a plus sign is written whenever the number of floors are not shown fully, and the term ‘tentative’ in written whenever there is no sure answer about how many floors does this specific building have. Number of buildings and shape of buildings is the categories that define the school’s shape, some schools have two or more buildings that are either separated or attached, also some schools are of different shapes (T-shape / U-shape / L-shape / Square / Rectangle / Zigzag). Date of construction, as stated before, is a category that was not used due to the fact that no data was found on all schools except for only one, which will be discussed later in the analysis Chapter. The operating status shows that all public schools present in municipal Beirut are still operating (the term ‘O’ is written as abbreviation) normally. Finally, the status from the blast show if the school’s building is affected by Beirut’s port blast (the term ‘NA’ is written as abbreviation for Not Affected).

In order to start the process of filtering out in a proper scientific manner, this approach is chosen to be conducted in this research. Therefore, all these data are collected on the public schools, then they are classified and documented in an excel sheet. The complete excel sheet is included in the Appendix. For the sake of space here, table 4 shows one example of one public school, the data collected according to the categories.

| | |
|---|---|
| **Code / Numbering** | 1 |
| **Cadaster** | Achrafieh fonciere |
| **School Name** | Uruguay First Achrafieh Public School for Boys |
| **Latitude** | 33.87902908 |
| **Longitude** | 35.5297956 |
| **Area of rooftop (m2)** | 1500 |
| **Zone / Category** | Next to High Rise / Next to Highway |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Five |
| **Number of Buildings** | One |
| **Shape of Building** | T-shape |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 4 - Example of categorization of Public School #1 (Prepared by: author)*

*4.2.2. Documenting and presenting the data collected on the six chosen public schools*

Going back to section 4.1., six public schools are chosen after the first filtering out process. These six public schools are located in two different cadasters of municipal Beirut, Ashrafieh fonciere and Ras Beirut fonciere. All six schools are found far from the existing green areas or patches in the city region, as shown in Chapter 3, and also they are not affected by the 4$^{th}$ of August blast of Beirut's port. (Table 1)

Tables 5 until 10 present the data collected about these six schools using Google Earth, following the different categories defined before in the previous section 4.2.1. Each table shows the collected data of each school of the chosen six respectively, starting by table 5 presenting public school #5.

| | |
|---|---|
| **Code / Numbering** | 5 |
| **Cadaster** | Achrafieh fonciere |
| **School Name** | El Achrafieh First for Boys Secondary Public school |
| **Latitude** | 33.88372915 |
| **Longitude** | 35.51765456 |
| **Area of rooftop (m2)** | 1300 |
| **Zone / Category** | Next to High Rise |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Four |
| **Number of Buildings** | One |
| **Shape of Building** | Rectangle |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 5 - Public School #5 data (Prepared by: author)*

| | |
|---|---|
| **Code / Numbering** | 8 |
| **Cadaster** | Achrafieh fonciere |
| **School Name** | Lor Mghayzil for Girls Secondary Public School |
| **Latitude** | 33.88988215 |
| **Longitude** | 35.5283736 |
| **Area of rooftop (m2)** | 1300 |
| **Zone / Category** | On a Hill |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Four + |
| **Number of Buildings** | Two attached |
| **Shape of Building** | Zigzag |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 6 - Public School #8 data (Prepared by: author)*

| | |
|---|---|
| **Code / Numbering** | 9 |
| **Cadaster** | Achrafieh fonciere |
| **School Name** | El Achrafieh Mixed Intermediate Public school |
| **Latitude** | 33.89145436 |
| **Longitude** | 35.5287216 |
| **Area of rooftop (m2)** | 600 |
| **Zone / Category** | Next to Highway |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Three |
| **Number of Buildings** | One |
| **Shape of Building** | L-shape |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 7 - Public School #9 data (Prepared by: author)*

| | |
|---|---|
| **Code / Numbering** | 10 |
| **Cadaster** | Achrafieh fonciere |
| **School Name** | Karm El Zeitoun Mixed Intermediate Public School |
| **Latitude** | 33.88896819 |
| **Longitude** | 35.5264527 |
| **Area of rooftop (m2)** | 500 |
| **Zone / Category** | Next to Highway |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Three |
| **Number of Buildings** | Two attached |
| **Shape of Building** | T-shape |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 8 - Public School #10 data (Prepared by: author)*

| | |
|---|---|
| **Code / Numbering** | 50 |
| **Cadaster** | Ras Beyrouth fonciere |
| **School Name** | Ras Beirut First Mixed Public School (maybe Jaber Ahmad Al soba7) |
| **Latitude** | 33.896252 |
| **Longitude** | 35.47353 |
| **Area of rooftop (m2)** | 850 |
| **Zone / Category** | Crowded Neighborhood |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Four + |
| **Number of Buildings** | One |
| **Shape of Building** | U-shape |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 9 - Public School #50 data (Prepared by: author)*

| | |
|---|---|
| **Code / Numbering** | 51 |
| **Cadaster** | Ras Beyrouth fonciere |
| **School Name** | Al Manara Intermediate Public School for Girls |
| **Latitude** | 33.89429218 |
| **Longitude** | 35.47495261 |
| **Area of rooftop (m2)** | 900 |
| **Zone / Category** | Crowded Neighborhood |
| **Type of Rooftop** | Flat |
| **Number of Floors (+GF)** | Four + |
| **Number of Buildings** | One |
| **Shape of Building** | Rectangle |
| **Date of Construction** | NOT FOUND |
| **Operating Status** | O (Operating) |
| **Status from the Blast** | NA (Not Affected) |

*Table 10 - Public School #51 data (Prepared by: author)*

### *4.2.3. Comparing the six chosen schools; selecting two schools from them*

After piling up all the collected data on these six schools, and presenting them in tables 5 until 10, a process of comparison is conducted, in order to filter out more schools and ending up with only two schools to study in this research. This process of comparison is based on the categories of data collected on each school, which are mentioned and explained in section 4.2. Also, the comparison process is conducted on each category alone, and then moving on to the next.

For example, comparing the data of the first category of all six schools, shows the different areas of rooftops in square meter. As shown in table 11, all six schools' rooftops' areas are compiled together in order to facilitate the comparison.

| **Code** | #5 | #8 | #9 | #10 | #50 | #51 |
|---|---|---|---|---|---|---|
| **Area of Rooftop (m2)** | 1300 | 1300 | 600 | 500 | 850 | 900 |

*Table 11 - Comparison of areas of rooftops (Prepared by: author)*

Comparing the areas, we can find a maximum number and a minimum number. The maximum area of rooftop is 1300 square meter, it belongs to schools #5 and #8, and it is highlighted in orange in table 11. While the minimum area of rooftop is 500 square meter, it belongs to school #10 and it is highlighted in blue in the same table above.

The second category to be compared is the zoning or the context in which the school building exists. (Table 12)

| **Code** | #5 | #8 | #9 | #10 | #50 | #51 |
|---|---|---|---|---|---|---|
| **Zone / Category** | Next to High Rise | On a Hill | Next to Highway | Next to Highway | Crowded Neighborhood | Crowded Neighborhood |

*Table 12 - Comparison of zoning or context (Prepared by: author)*

As shown in the above table (12), each zoning is associated with a color; 'next to high rise' is in orange, 'on a hill' is in gray, 'next to highway' is in yellow, 'crowded neighborhood' is in green; in order to help facilitate the comparison process, and identify the similarities and differences. Therefore, school #5 is orange, school #8 is gray, schools #9 and #10 are yellow, and schools #50 and #51 are green.

The third category in the comparison process is the type of rooftop of all six public schools. As shown in table 13, all six schools have flat rooftops, therefore, they are all eligible to be considered in this study.

| **Code** | #5 | #8 | #9 | #10 | #50 | #51 |
|---|---|---|---|---|---|---|
| **Type of Rooftop** | Flat | Flat | Flat | Flat | Flat | Flat |

*Table 13 - Comparison of types of rooftops (Prepared by: author)*

The fourth category is the number of floors of each school building of the six chosen ones. This number of floors includes the ground floor. (Table 14)

| **Code** | #5 | #8 | #9 | #10 | #50 | #51 |
|---|---|---|---|---|---|---|
| **Number of Floors (+GF)** | 4 | 4+ | 3 | 3 | 4+ | 4+ |

*Table 14 - Comparison of number of floors of all six schools (Prepared by: author)*

The maximum number of floors, including the ground floor, is four floors and above, and is highlighted in orange in the table above. The minimum number of floors, including the ground floor, is three and is highlighted in blue in the table.

The number of buildings that constitute the school building is the fifth category to be compared. Table 15 shows this comparison.

| **Code** | #5 | #8 | #9 | #10 | #50 | #51 |
|---|---|---|---|---|---|---|
| **Number of Buildings** | One | Two attached | One | Two attached | One | One |

*Table 15 - Comparison of number of buildings (Prepared by: author)*

As shown in table 15, schools #5, #9, #50 and #51 are constituted of one building each, and they are highlighted in orange, while schools #8 and #10 are constituted of two attached buildings each and are highlighted in blue.

The sixth category to be compared is the shape of the school's building. As shown in table 16, there are five shapes. The rectangle shape is highlighted in orange and it is the shape of schools #5 and #51. The zigzag shape is highlighted in gray and it is the shape of school #8. The L-shape is highlighted in yellow and it is the shape of school #9. The T-shape is highlighted in blue and it is the shape of school #10. The u-shape is highlighted in green and it is the shape of school #50.

| **Code** | #5 | #8 | #9 | #10 | #50 | #51 |
|---|---|---|---|---|---|---|
| **Shape of Building** | Rectangle | Zigzag | L-shape | T-shape | U-shape | Rectangle |

*Table 16 - Comparison of the shape of buildings (Prepared by: author)*

The last three categories to be compared are the same for all six public schools; the date of construction is not known due to not found data, the operating status of all six schools is the same (they are all operating normally), and the status from the 4$^{th}$ of August blast of Beirut's port for all six schools is also the same for all (they are all not affected by the blast). Therefore, there is no need for comparison.

In order to compare these six schools more accurately, all data collected and presented previously in this section is compiled together in table 17. In this table, the six categories mentioned above, area of rooftop, zone or context, type of rooftop, number of floors, number of buildings and shape of the building, are presented and coded also in colors, in order to understand the comparison in an easier manner. The colors are put according to the common terms between schools in each category.

| Code | Area of Rooftop (m2) | Zone / Category | Type of Rooftop | Number of Floors (+GF) | Number of Buildings | Shape of Building |
|---|---|---|---|---|---|---|
| **#5** | 1300 | Next to High Rise | Flat | 4 | One | Rectangle |
| **#8** | 1300 | On a Hill | Flat | 4+ | Two attached | Zigzag |
| **#9** | 600 | Next to Highway | Flat | 3 | One | L-shape |
| **#10** | 500 | Next to Highway | Flat | 3 | Two attached | T-shape |
| **#50** | 850 | Crowded Neighborhood | Flat | 4+ | One | U-shape |
| **#51** | 900 | Crowded Neighborhood | Flat | 4+ | One | Rectangle |

*Table 17 - Compilation of all data and comparison (Prepared by: author)*

As shown in the table above, the maximum and the minimum area of rooftop are chosen, in order to have different approaches of design or proposals at the end. Therefore, the maximum areas are highlighted in red (1300 m2), and the minimum area is highlighted in blue (500 m2). Accordingly, schools #5, #8 and #10 are in consideration here. Going back to Chapter 3 in section 3.2.1. in table 1, these three schools are located in Ashrafieh district, while the two schools #50 and #51 which are located in Ras Beirut district are not considered. In order to choose two schools to study in the next section of this Chapter, these two schools need to be in different regions in municipal Beirut, so each school can be therefore considered as a model that represents a wide number of other schools, so, the design proposed at the end of this research for each school can be applied to the other public schools in the municipal Beirut and even the cities next to it, since this is a research conducted on public schools that are located in coastal areas in Lebanon. Hence, school #5 or #8 are considered to one of the two chosen schools, being located in the Ashrafieh district, while the second schools to be chosen should be schools #50, since it is located in Ras Beirut area and has the minimum area of rooftop between the two schools of this region. Therefore, school #50, with its area of 850 m2, is highlighted in a lighter shade of blue.

Accordingly, school #50 is one of the two schools that should be chosen to be studied in the next section of this Chapter, having a considerably small area of rooftop, being in a crowded neighborhood, having a flat roof, having more than four floors including the ground floor, and consisting of one building that is of U-shape.

Therefore the comparison process continues with schools #5 and #8, and the elimination process takes place in each category according to the comparison with the school #50, which is already chosen.

Both schools have a flat rooftop, so there is no comparison here.

School #5 is located next to a high rise, while school #8 is located on a hill; these two contexts are different of that of school #50, which is located in a crowded neighborhood, so both schools can e considered here in this comparison.

School #5 has four floors including the ground floor, while school #8 has more than four floors including the ground floor. While comparing with school #50, which has more than four floors including the ground floor, school #5 can be considered here to be chosen, since it is consisting of only four floors including the ground floor. Therefore, it is highlighted in green in table 17.

Moreover, school #5 is comprised of only one building, while school #8 is comprised of two attached buildings. While comparing with school #50, which is comprised of only one building, school #8 can be considered here to be chosen, since it is comprises of two attached buildings. Therefore, it is highlighted in yellow in table 17.

The building of school #5 is of rectangle shape, while the building of school #8 is of zigzag shape. While comparing with school #50, a building of a U-shape, both schools #5 and #8 can be considered here in this comparison.

In conclusion, the comparison process can only occur in the categories of number of floors, number of buildings and shape of the building. However, choosing school #5 along with school #50 as the final two schools to be studied in the next section of this Chapter, may lead to a similar design proposal since both public schools consist of only one building. In addition, the building of school #5 is of rectangle shape, which is really similar to the shape of the building of school #50 which is a U-shape (3 continuous rectangles). Therefore, school #8 should be chosen along with school #50, as the two chosen public schools to conduct this research about, in order to have two different approaches or proposals of designs that can be applied to a wide number of other public schools in the region of municipal Beirut and also other coastal areas in Lebanon. Accordingly, school #8 is highlighted in a lighter shade of orange in table 17.

Figure 30 shows school #8, while figure 31 shows school #50. Both photos are captured during the site visit mentioned in the previous Chapter in section 3.3.

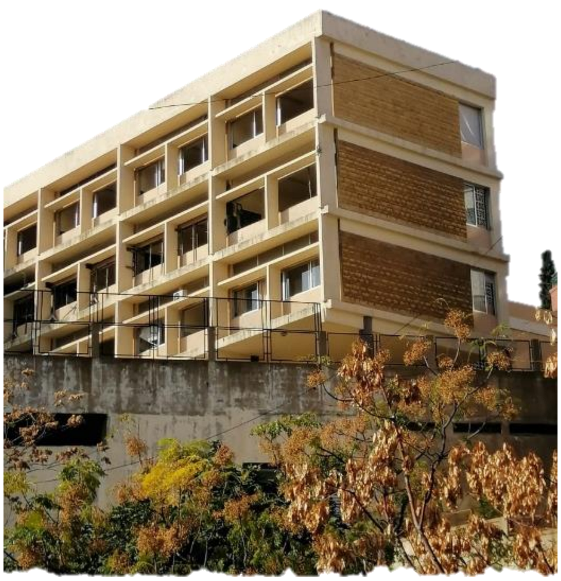


*Figure 31 - School #8 (Captured by: author)*

*Figure 32 - School #50 (Captured by: author)*

## 4.3. Briefing on Schools #8 and #50

### *4.3.1. Briefing on School #8: Lor Moughayzel Public School – Ashrafieh District*

*-Historical glance about the establishment of the school*

In the year of 1953, this school was founded and was named back then 'the new high school for girls'. It was first located in Sersok quarter, then in 1969, Mr. Salim Shahroury constructed the new building for this school in Fassouh quarter on St. Peter and Paul Street (Schoolnet, n.d.). This new building is the subject in this study. (Figure 33)


*Figure 33 - Lor Moughayzel Public School – Ashrafieh District*

In the year of 1997, the Minister of Education Jean Obeid back then, ordered to change the school's name to 'Lor Moughayzel High School for girls', due to the request applied by "The Lebanese Women University Committee'. Laure Moghaizel was a lebanese lawyer and a prominent advocate for women's rights. (L'orient-Le Jour, 1997) (Schoolnet, n.d.)

As for the building of the school, it is composed of eight floors (including the ground floor acting as a playground, three underground parking, and four floors above ground having the class rooms, the labs and the conference rooms). Due to the topography of the location, we can see four floors including the ground floor above ground from one side of the building which is where the entrance is located, while we can see six floors including the ground floor from the opposite side of the building, facing the highway; this is considered unrelated to the design process because the topography is not taken into consideration during the study and analysis process due to the fact that it does not affect the rooftop in any way, which is the target element of this study. In addition, the rooftop is currently not used for anything other than having a water storage and a maintenance room; therefore, it is accessed only by the maintenance team of the school. Figure 34 is a real photo of the school, and figure 35 is a rendered 3D model of the school.

*Figure 34 - Lor Moughayzel Public School - Ashrafieh District - Entrance view (Captured by: Angelo Baaklini, 2021)*

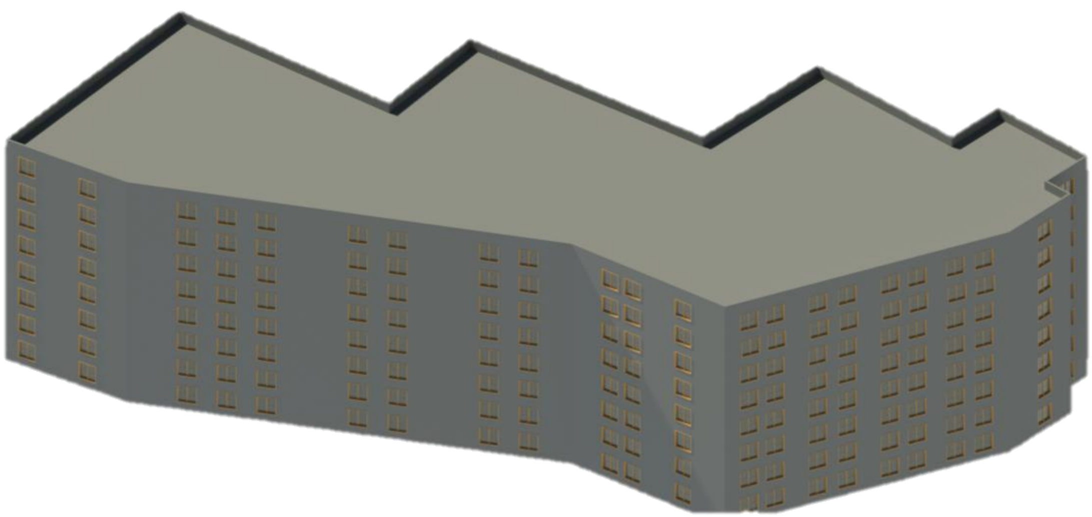


*Figure 35 - Lor Moughayzel Public School - Ashrafieh District – 3D model (Prepared by: author)*

*-The school location in town*

The school building is located at the heart of Ashrafieh district, surrounded by various private schools such as *Sagesse, Sacred Heart, Nazareth, Zahret el Ihsan* and many more. As a result of being the only public school in this approximate distance, 'Lor Moughayzel High School for girls' prides itself having a special and prominent place in municipal Beirut. (Schoolnet, n.d.)

The school reflects a space of 'a new developed educational act' where the main core interest is creating free, democratic and responsible citizens, focusing on human rights as well as the good human values. (Schoolnet, n.d.)

In addition, the students of this school come from different parts of Beirut and various regions in Lebanon. (Schoolnet, n.d.)

*-Type of program given*

This school is a high school for girls only. According to Schoolnet.edu.lb, 'the new Curriculum is applied in the intermediate Cycle and the Secondary Cycle in all its branches'. The main foreign language taught is French, although there are three languages that are taught in this school and they are Arabic, French and English. (Schoolnet, n.d.)

Moreover, the Educational Center for Research and Development (CRDP) stated in its most recent report in 2021 on all public schools in Lebanon that 'Lor Moughayzel High School for girls' has three hundred and eighty (380) students enrolled in total in the academic year of 2020-2021, as well as it has forty four (44) instructors and nine (9) staff members working in the administration office. (CRDP, 2021)

*-Accomplishments and activities done in terms of Sustainability*

Lor Moughayzel High School has been listed in the 'Green Schools' in the MENA region. The school acquired a certification of 'Green Schools, Bronze' which is the first level of certification, scoring twenty (20) to twenty nine (29) GPs meaning Green Points; however, the certification is expired. The Green Schools certification program guides the private and public schools in MENA region to a true sustainability engagement on three main levels which are the building measures, the curriculum and students' engagement, and the administration practices. The program is divided into six categories being waste, green spaces, water efficiency, energy efficiency, sustainability education and innovation, and finally health and safety. In each category the participating school scores GPs based on a checklist of sustainability solutions. (Green Schools, n.d.)

*-School's building: 3D model and plan*

Figure 36 shows the plan of the school, showcasing the rooftop and its area.

Following the 3D model mentioned in Chapter 3, which this whole study is based on, figures 37 – 39 show the different rendered views of Lor Moughayzel School in Ashrafieh district, in its context of roads and neighboring buildings.

In addition, figure 40 shows the rendered 3D model of the school without context and without topography, in order to showcase the building alone.

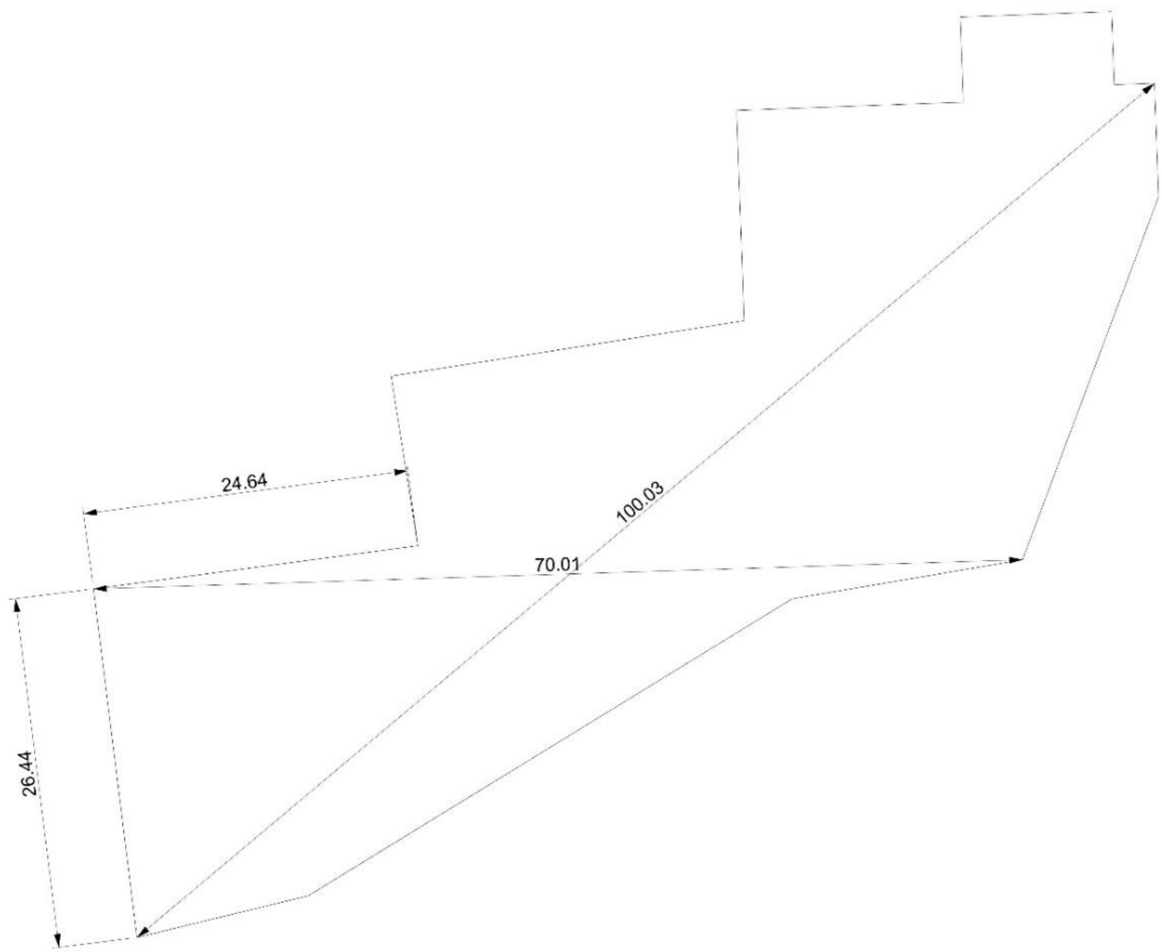



*Figure 36 - Lor Moughayzel High School for girls, Ashrafieh - Rooftop Plan (units in meter) (Prepared by: author)*

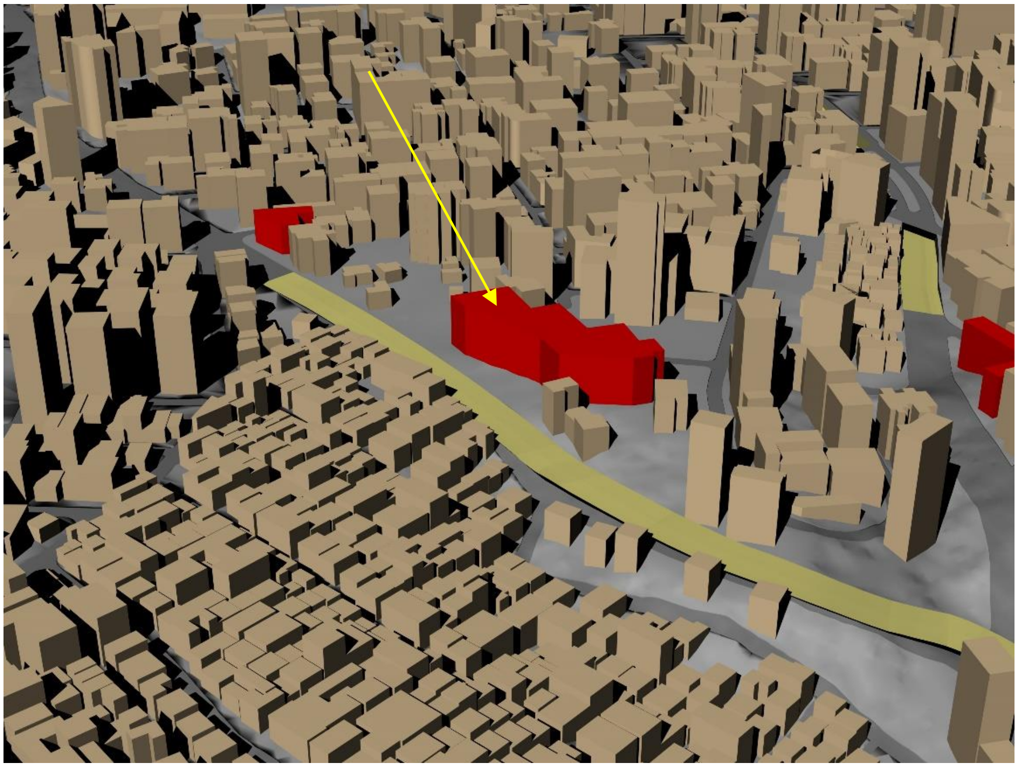


*Figure 37 - Lor Moughayzel High School for girls, Ashrafieh - View 1 (Prepared by: author)*

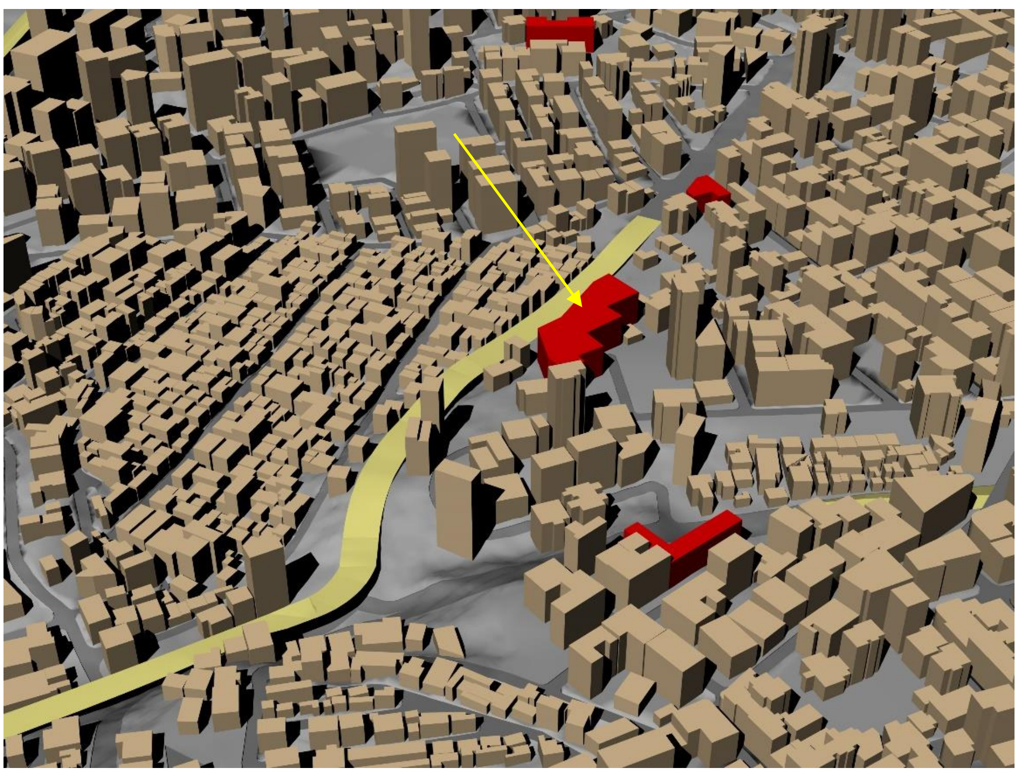


*Figure 38 - Lor Moughayzel High School for girls, Ashrafieh - View 2 (Prepared by: author)*

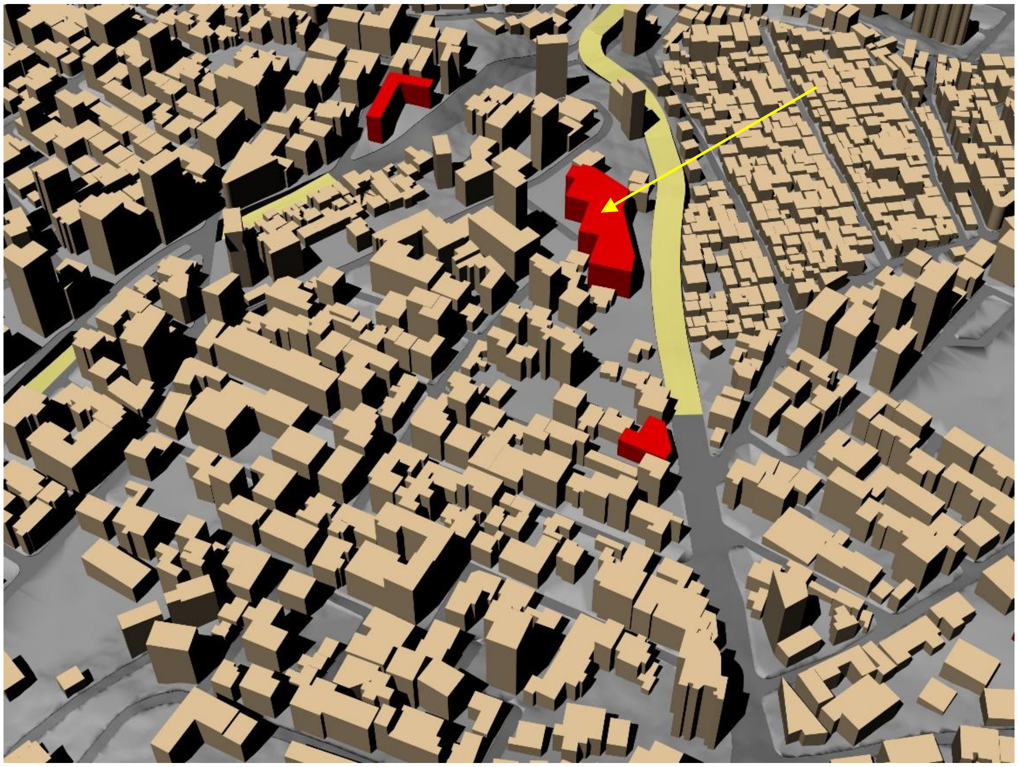


*Figure 39 - Lor Moughayzel High School for girls, Ashrafieh - View 3 (Prepared by: author)*

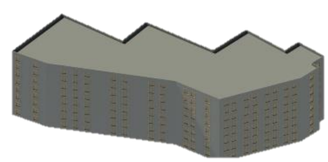


*Figure 40 - Lor Moughayzel High School for girls, Ashrafieh – 3D model rendered (Prepared by: author)*

### *4.3.2. Briefing on School #50: Ras Beirut Mixed Public School* or *Jaber Ahmad Al Sabah Public School – Ras Beirut District*

*-Historical glance about the establishment of the school*

In the year of 2009, this school's building was constructed and was named back then 'Ras Beirut First public middle school'. It is originally located in the same location it is now (figure 41). The building in Figure 42 is the subject of this study. (Figure 42)

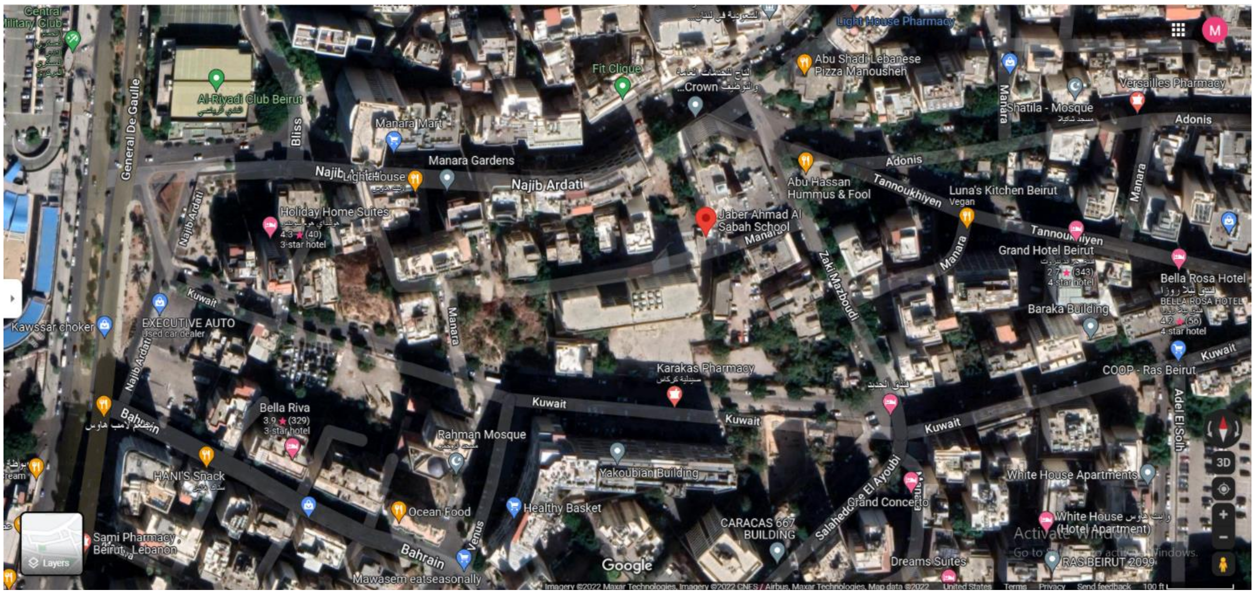



*Figure 41 - Jaber Ahmad Al Sabah Public School – Ras Berut District*

Later on, the Minister of Education, ordered to change the school's name to 'Jaber Ahmad Al Sabah Public School' from its original name which was 'Ras Beirut First public middle school', due to the funding presented by Sheikh Jaber Ahmad Al Sabah to the school. Sheikh Jaber Ahmad Al Sabah was Emir of Kuwait from 1977 untill 2006. (Etheredge, 2011) (Schoolnet, n.d.)

A brief interview has been inducted with Ms. Ghada Azar, the secretary at this school. During the interview, various questions were asked about the name of the school, the year of construction of the building, the type of program offered, the primary foreign language used, along with some characteristics about the building itself such as the number of floors, the number of class rooms, and the current usage of the rooftop. Ms. Azar provided some brief data about the school, especially the facts about the building having nine floors (including the ground floor acting as a playground, two underground parking, and six floors above ground having the class rooms, the labs and the conference rooms). In addition, the rooftop is currently not used for anything other than having a water storage and a maintenance room; therefore, it is accessed only by the maintenance team of the school. Figure 42 is a real photo of the school, and figure 43 is a rendered 3D model of the school.

*Figure 42 - Jaber Ahmad Al Sabah Public School – Ras Berut District - Entrance view (Extracted from: kuna.net.kw, 2018)*

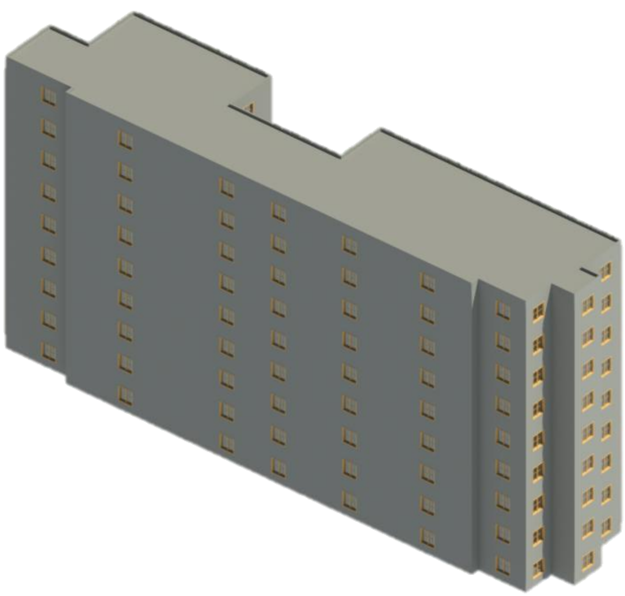


*Figure 43 - Jaber Ahmad Al Sabah Public School – Ras Berut District - 3D model (Prepared by: author)*

*-The school location in town*

The school building is located at the heart of Ras Beirut district, surrounded by various private schools such as *International College, American Community School Beirut, College Protestant Français, Ras Beirut International School* and many more. In addition, the massive presence of the *American University of Beirut (AUB)* in the region has a great impact on transforming this region into an educational hub in municipal Beirut. As a result of being the only public school in this approximate distance, 'Jaber Ahmad Al Sabah Public School' prides itself for having a special and prominent place in municipal Beirut, especially being one of the rarest public schools in the district. (Schoolnet, n.d.)

In addition, the students of this school come from different parts of Beirut and various regions in Lebanon, which results in creating a widely diverse demographic community. (Schoolnet, n.d.)

*-Type of program given*

This school is a middle school for boys and girls, so it is mixed. According to Schoolnet.edu.lb, 'the new Curriculum is applied in the intermediate Cycle and the Secondary Cycle in all its branches'. The main foreign language taught is English, although there are three languages that are taught in this school and they are Arabic, French and English. (Schoolnet, n.d.)

Moreover, the Educational Center for Research and Development (CRDP) stated in its most recent report in 2021 on all public schools in Lebanon that 'Jaber Ahmad Al Sabah Public School' has four hundred and seventy nine (479) students enrolled in total in the academic year of 2020-2021, as well as it has twenty nine (29) instructors and eight (8) staff members working in the administration office. (CRDP, 2021)

*-Accomplishments and activities done in terms of Sustainability*

No data available.

*-School's building: 3D model and plan*

Figure 44 shows the plan of the school, showcasing the rooftop and its area.

Following the 3D model mentioned in Chapter 3, which this whole study is based on, figures 45 – 47 show the different rendered views of Jaber Ahmad Al Sabah Public School in Ras Beirut district, in its context of roads and neighboring buildings.

In addition, figure 48 shows the rendered 3D model of the school without context and without topography, in order to showcase the building alone.

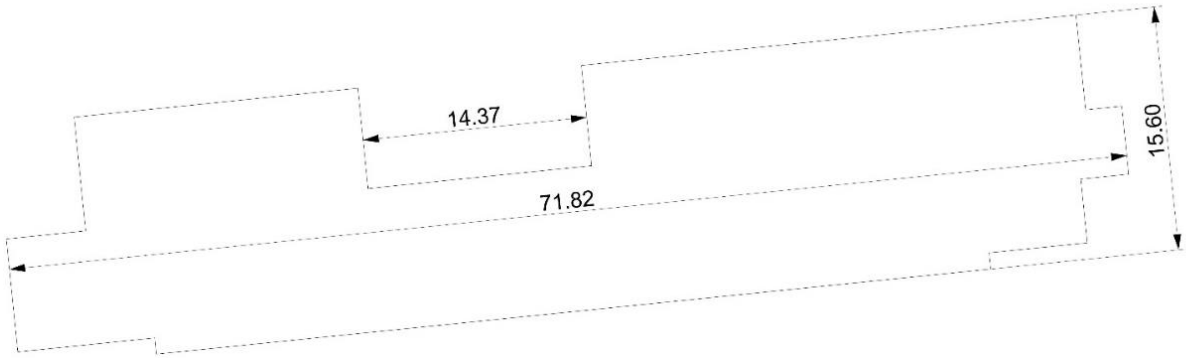



*Figure 44 - Jaber Ahmad Al Sabah Public School, Ras Beirut- Rooftop Plan (Prepared by: author)*

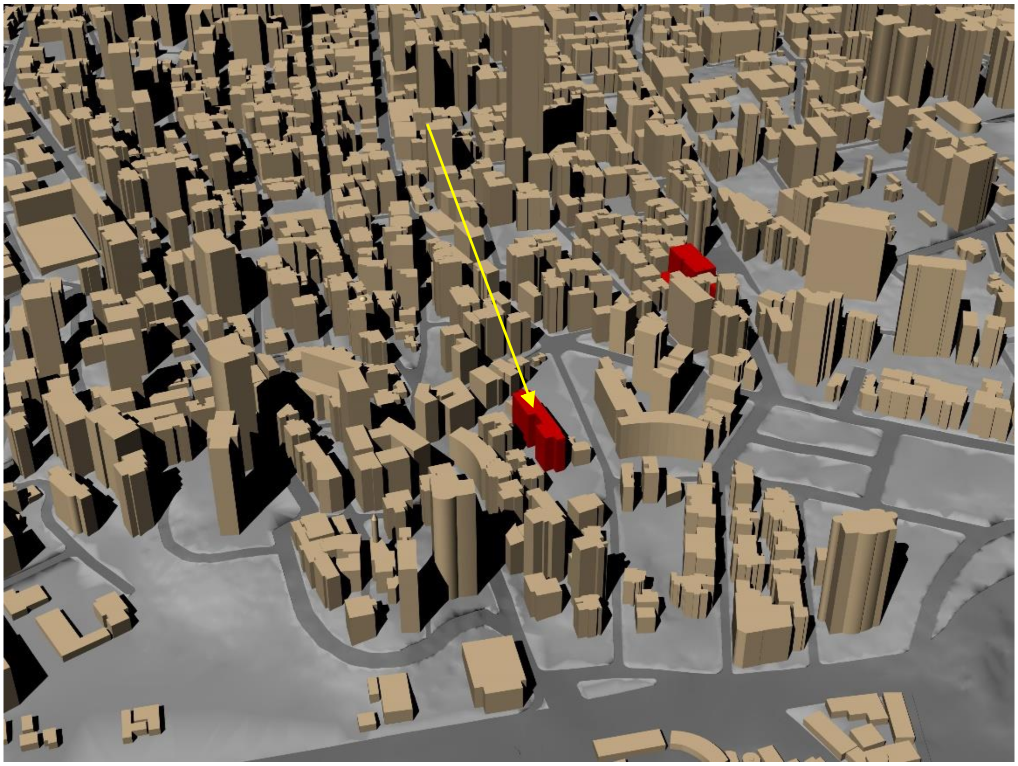


*Figure 45 - Jaber Ahmad Al Sabah Public School, Ras Beirut - View 1 (Prepared by: author)*

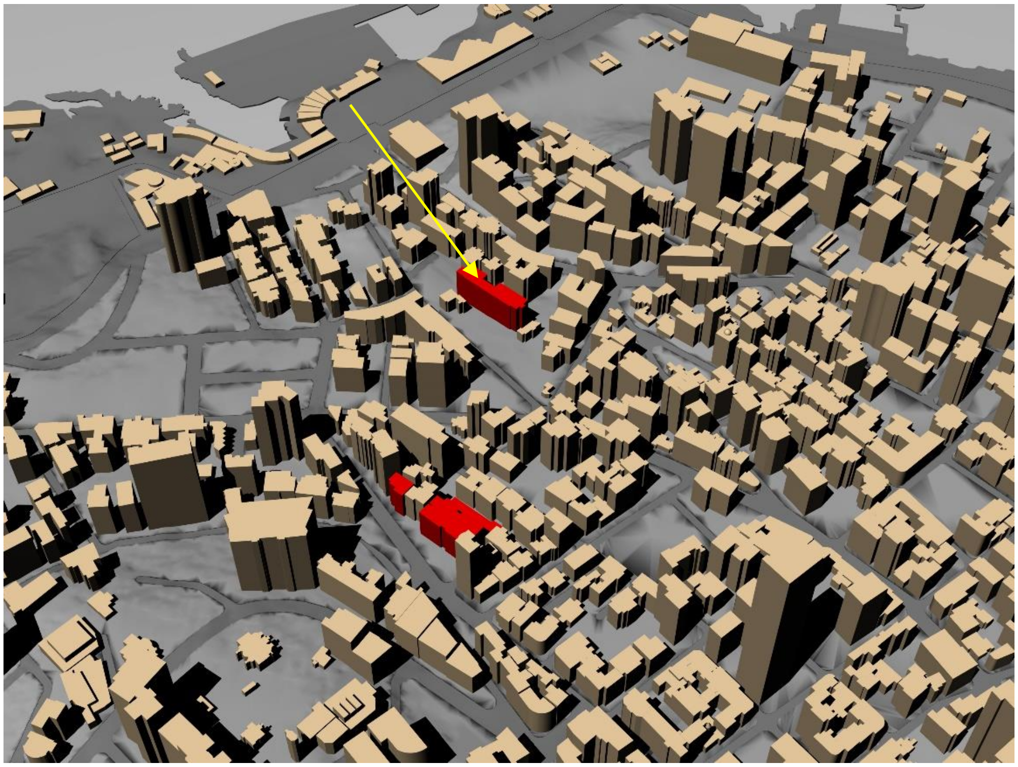


Figure 46 - Jaber Ahmad Al Sabah Public School, Ras Beirut - View 2 (Prepared by: author)

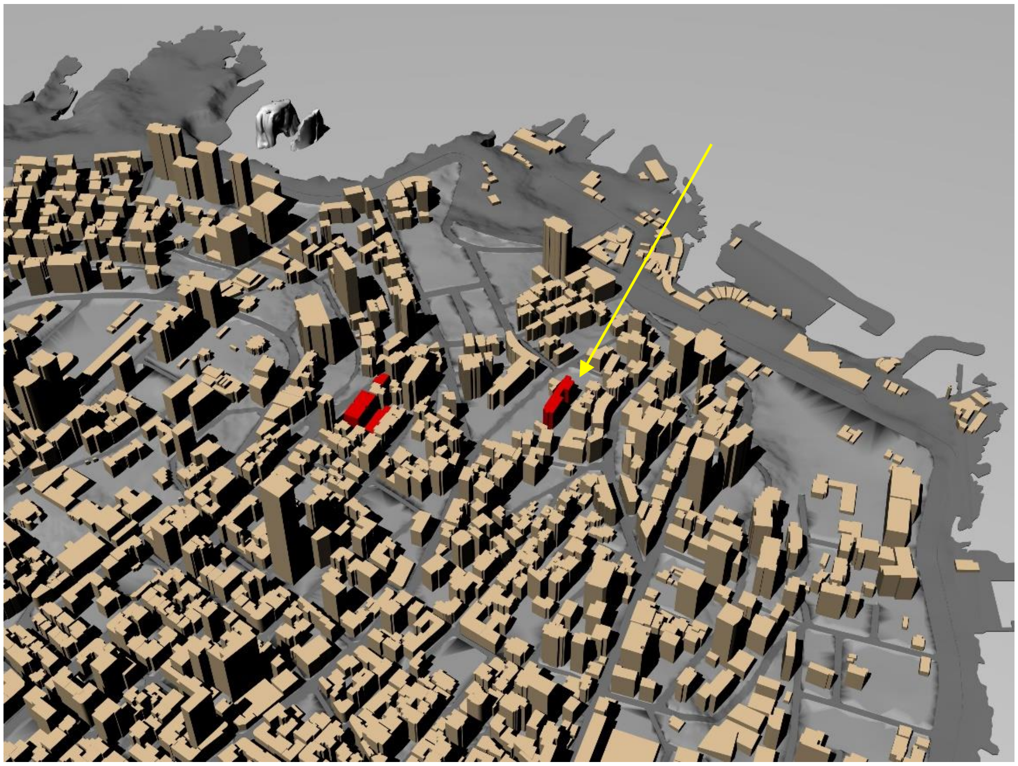


Figure 47 - Jaber Ahmad Al Sabah Public School, Ras Beirut - View 3 (Prepared by: author)

*Figure 48 - Jaber Ahmad Al Sabah Public School, Ras Beirut – 3D model rendered (Prepared by: author)*

## 4.4. Analysis and CFD analysis on Schools #8 and #50

In order to validate wind simulation research for the two public schools chosen in the previous section, school #8 and school #50, the base models of each school were drawn respectively in different files of Revit software and their respective locations are determined in each file. In addition, to understand the impact of the wind flow in the urban area around the school's building on the type of vegetation to be planted and considered for the proposals, I worked on three options of wind direction and velocity all based on one base-model, and each option shows the wind flow during a specific time period of the year.

The tools that I used are first **Revit** where I drew the base-model as conceptual massing, the school's building along with its approximate neighboring buildings to play as context, and the three options of rotation of the wind box according to the prevailing winds in the specified location (generated from the weather station characteristics in **Green Building Studio or gbs**). From there, I was able to introduce the model into **Insight 360**, where I was able to identify the energy cost, and also determine the prevailing winds from **gbs**. Finally, **CFD** is used in order to study the wind flow in this location, and how each the buildings are affected by the different wind flow and direction around the year.

I documented the results below in sections and sub-sections, as well as the explanation of the base-model such as the location, true North vs. project North, and finally concluded with a summary.

#### *4.4.1. School #8: analysis process (From Revit to CFD)*

##### *4.4.1.1. Base-model and Location*

As mentioned before, School #8, *Lor Moughayzel Public School* is located in Ashrafieh district, under the coordinates 33.88988215; 35.5283736 (data extracted from the sheet provided by the UNICEF as mentioned before in Chapter 3). This location is easily found by copying and pasting the coordinates into Google Maps.

The base-model is extracted from the 3D model of Municipal Beirut; it is basically the mentioned school's building in the center along with its neighboring buildings around it to represent the context which can either block or let the wind flow easily around the school's building and in particular the building's rooftop. Note that the model is simplified in order to have better results in CFD software, which means, all the buildings are on the same level so the topography is deleted, the roads are also deleted. (Figure 49)


*Figure 49 - School 8 with context 3D model (prepared by: author)*

After the base-model is drawn in Revit, the location is set following the same coordinates used to find the location of the school on Google Maps, and a weather station is also specified, having approximately the same altitude and climate as the school's location (figure 50). The weather station will give climate specifications of this particular location such as the wind flow, direction and velocity.

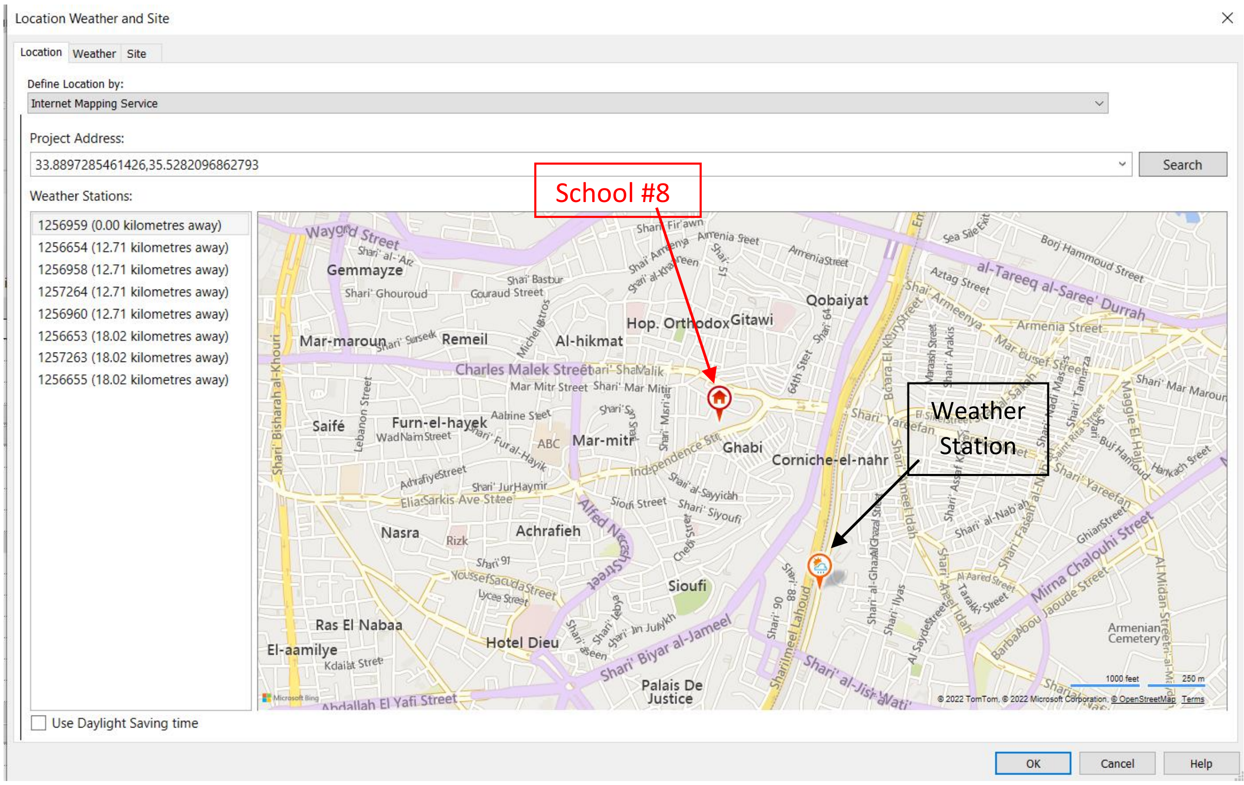



*Figure 50 - School #8 Location and Weather Station (prepared by: author)*

### *4.4.1.2. Energy Model / Insight 360 / Wind Rose*

After drawing the base-model in Revit and specifying the location and weather station, I have to create an ‘energy model’ of the base-model and optimize it (figure 51) in order for the project to be registered in Insight 360, and therefore in GBS (Green Building Studio) where the wind rose[5] will be available (figures 52-54). These steps are standard for this process of wind simulation of any project, either architectural or urban.

[5] Wind roses are graphical charts that characterize the speed and direction of winds at a location. Presented in a circular format, the length of each "spoke" around the circle indicates the amount of time that the wind blows from a particular direction. Colors along the spokes indicate categories of wind speed. (Wind Roses - Charts and Tabular Data, n.d.)

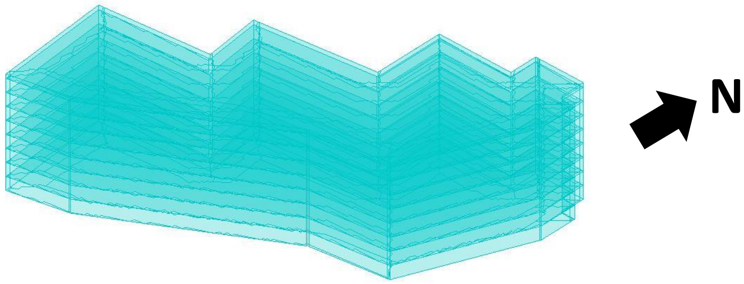



*Figure 51 - School #8: energy model (prepared by: author)*

In GBS, the specifications of the weather station that is determined are shown in different graphs, such as temperature, humidity, sky coverage, dry bulb, wind speed and direction and various other climate characteristics specific to the location. This study focuses on the wind flow research around the school’s building and rooftop, therefore, only the wind roses are studied and looked at from all these characteristics.

Figure 52 shows the wind rose of this specific location on annual basis, which means the wind direction and velocity or speed around the year. As shown in the figure, the prevailing wind or dominant wind is from South-East, with a velocity of 5.1-8.5 m/s.

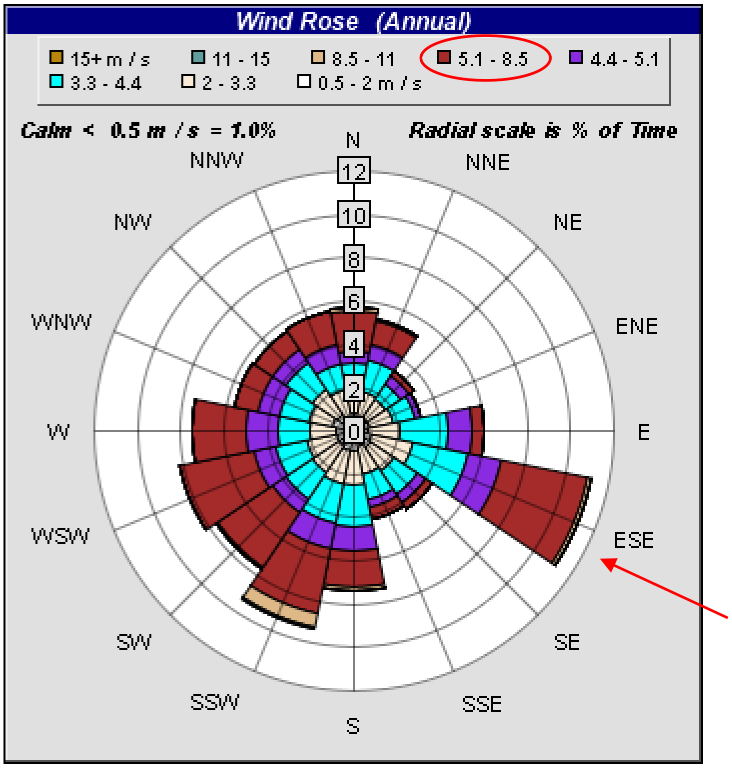


*Figure 52 - School #8: Wind Rose (annual) (extracted from: gbs.autodesk.com; prepared by: author)*

Figure 53 shows the wind rose of this specific location in winter, which means the wind direction and velocity or speed from January until March. As shown in the figure, the prevailing wind or dominant wind is from South-West, with a velocity of 8.5-11 m/s.

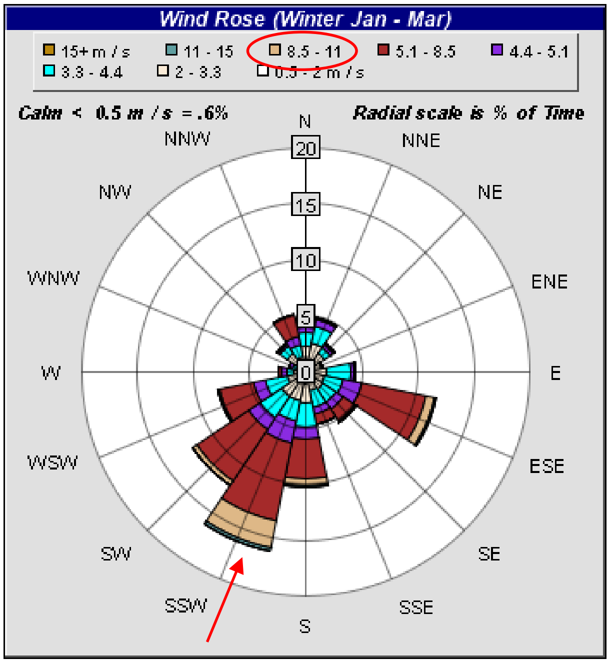



*Figure 53 - School #8: Wind rose (winter) (extracted from: gbs.autodesk.com; prepared by: author)*

Figure 54 shows the wind rose of this specific location in summer, which means the wind direction and velocity or speed from July until September. As shown in the figure, the prevailing wind or dominant wind is from West, with a velocity of 5.1-8.5 m/s.

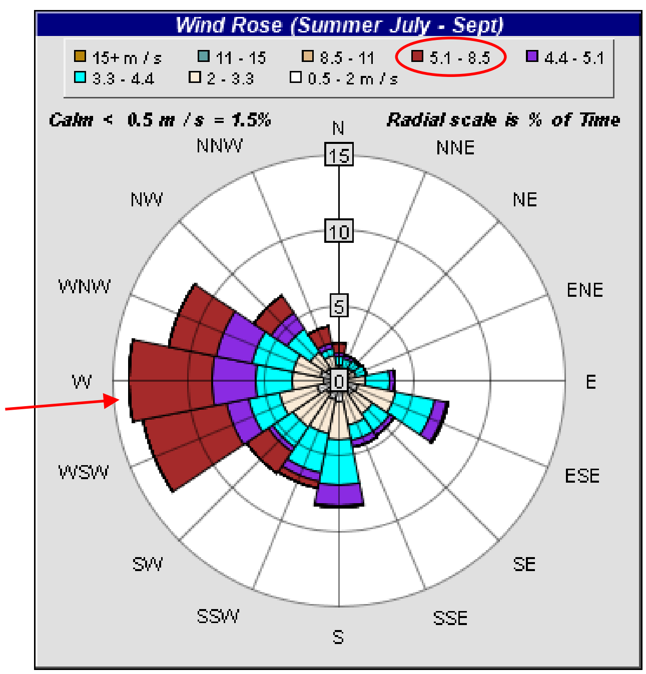



*Figure 54 - School #8: Wind rose (summer) (extracted from: gbs.autodesk.com; prepared by: author)*

### *4.4.1.3. Wind Box in Revit*

After understanding the wind direction and speed in this specific location, a box is drawn in Revit around the base-model, representing the 'wind box' or 'wind tunnel' in which the simulation of the wind flow will take place in CFD. In order to have an accurate simulation, the wind box is oriented following the direction of the prevailing wind or the dominant wind found from the wind rose in the previous sub-section.

Figure 55 shows the orientation of the wind box towards the South-East, according to the wind rose in figure 52, which is the annual wind flow. The orientation of the box is done according to a rotation of 30 degree angle clock-wise, as shown below in the figure.

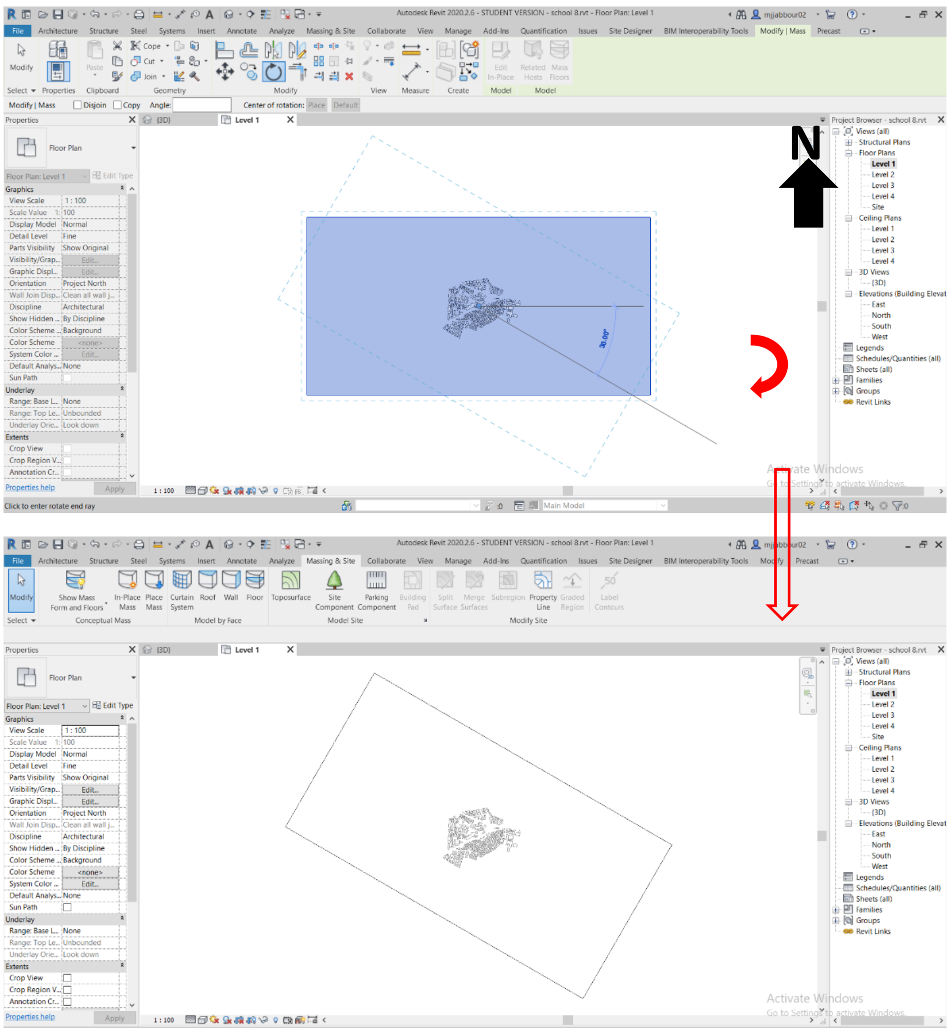



*Figure 55 - School #8: Orienting the wind box towards South-East (prepared by: author)*

Figure 56 shows the orientation of the wind box towards the South-West, according to the wind rose in figure 53, which is the wind flow during winter. The orientation of the box is done according to a rotation of 60 degree angle counter clock-wise, as shown below in the figure.

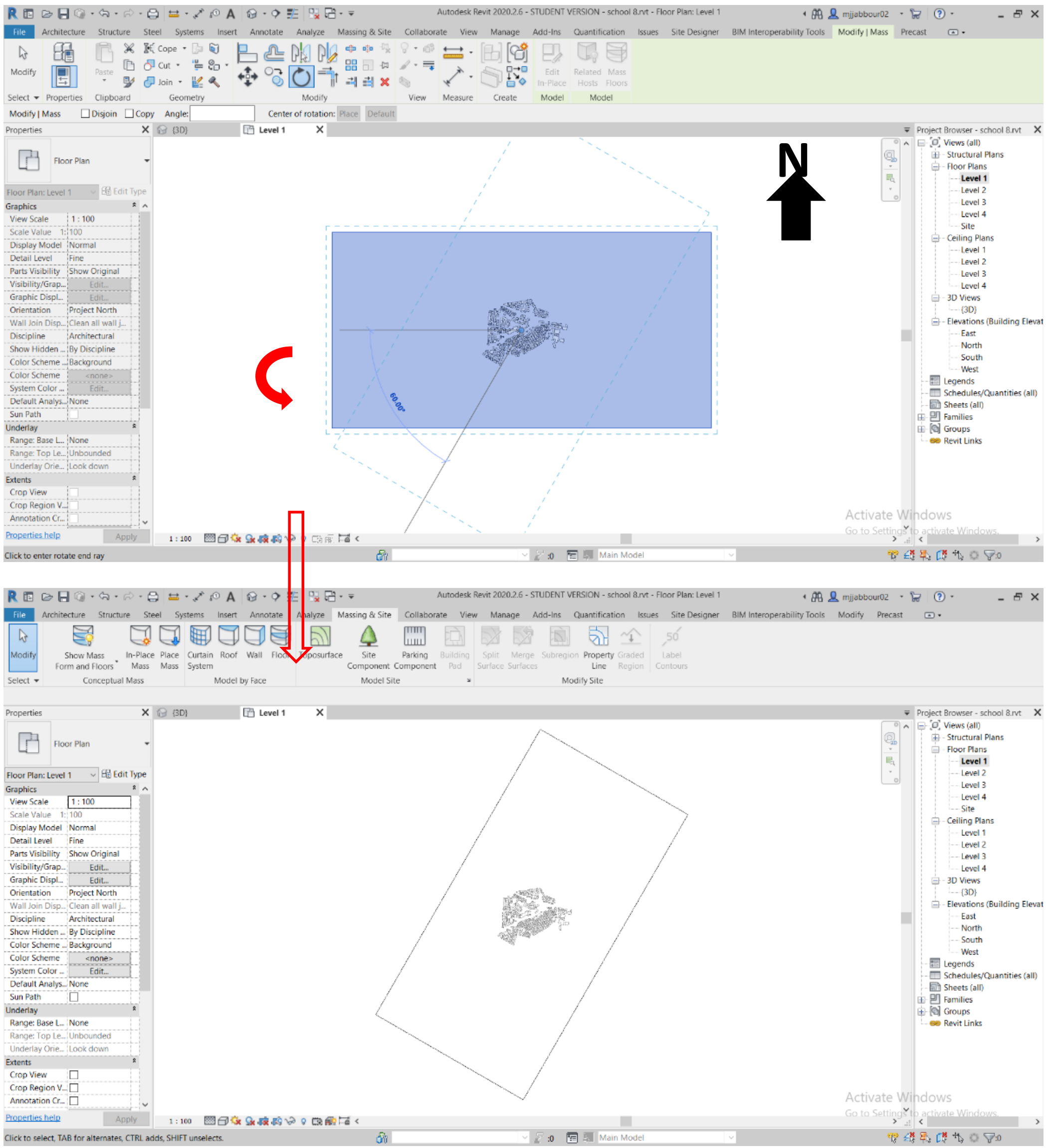



*Figure 56 - School #8: Orienting the wind box towards South-West (prepared by: author)*

Figure 57 shows the orientation of the wind box towards the West, according to the wind rose in figure 54, which is the wind flow during summer. The orientation of the box is done according to a rotation of 0 degree angle, as shown below in the figure.

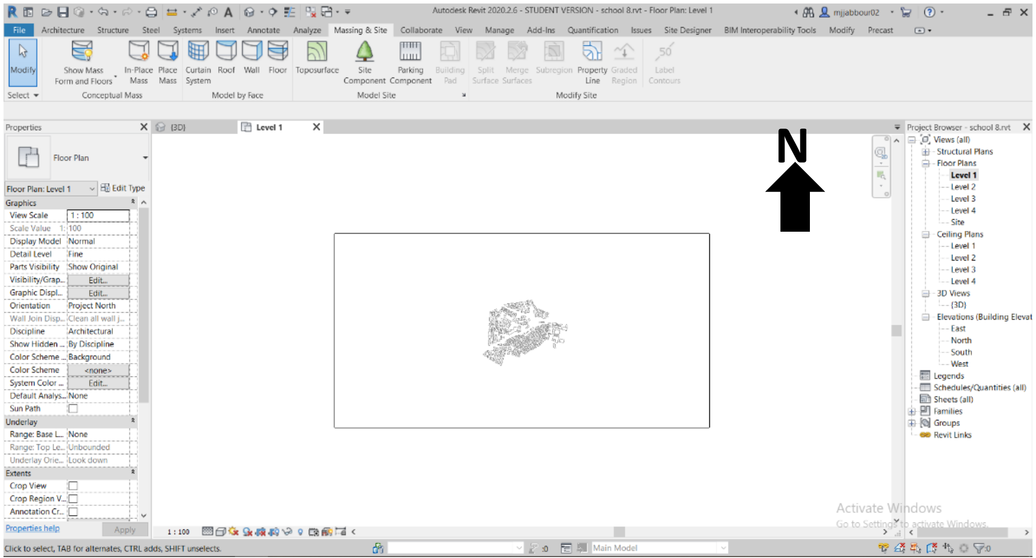



*Figure 57 - School #8: Orienting the wind box towards West (prepared by: author)*

### *4.4.1.4. Export to CFD / Conditions specifications*

After orienting the wind box in the three different directions, each file of Revit is exported to CFD as an extension '.acis'. Then, each file is opened in CFD alone.

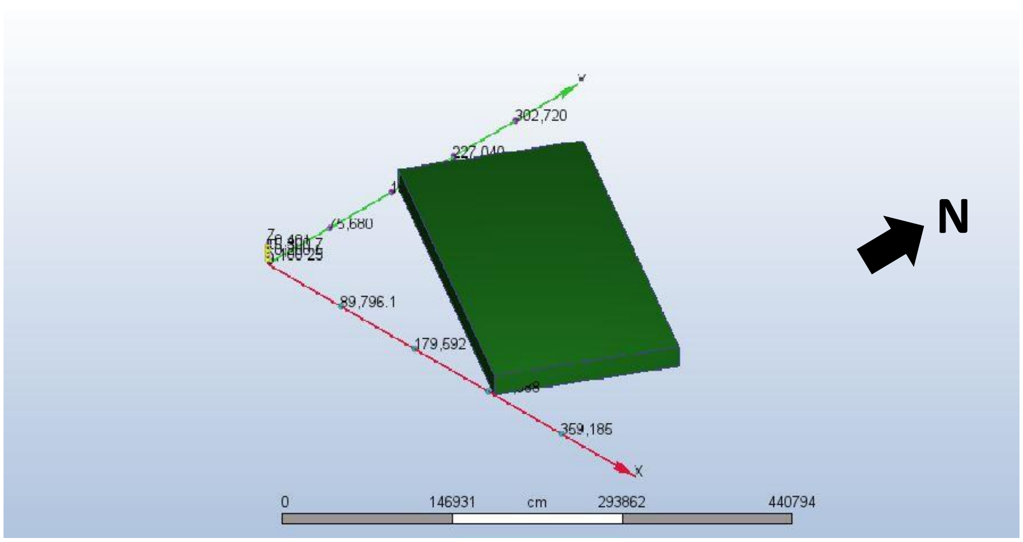



*Figure 58 - School #8: on CFD (prepared by: author)*

Figure 58 shows how the file is opened originally in CFD software. Then, we have to start specifying the conditions step by step. The steps following each other are highlighted in red in figure 59, an explained in the following.

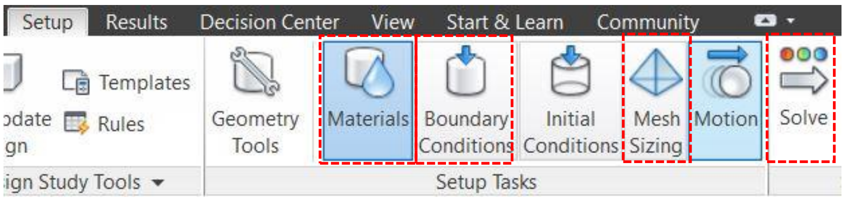



*Figure 59 - CFD Conditions (prepared by: author)*

First, I start with assigning the materials. The wind box is assigned as 'fluid' and then 'air'. (Figure 60)

The base-model is assigned as 'solid' and then 'concrete'. (Figure 61)

Note that here the openings of the buildings are disregarded, specifically the openings of the school's building, due to the fact that this study focuses only on the rooftop of the building, therefore, the openings are not needed; what is needed for an accurate simulation is the location of the buildings in relation to the surrounding buildings.

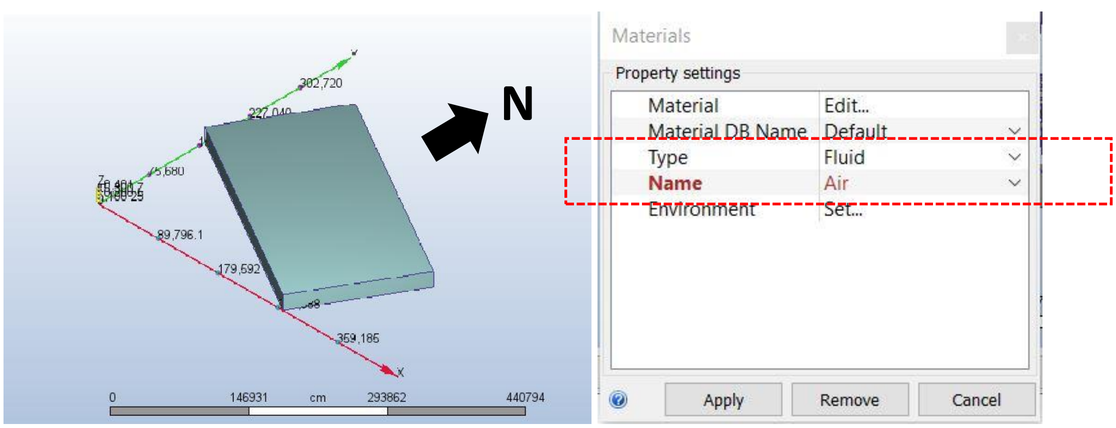



*Figure 60 - School #8: Air material for the wind box (prepared by: author)*

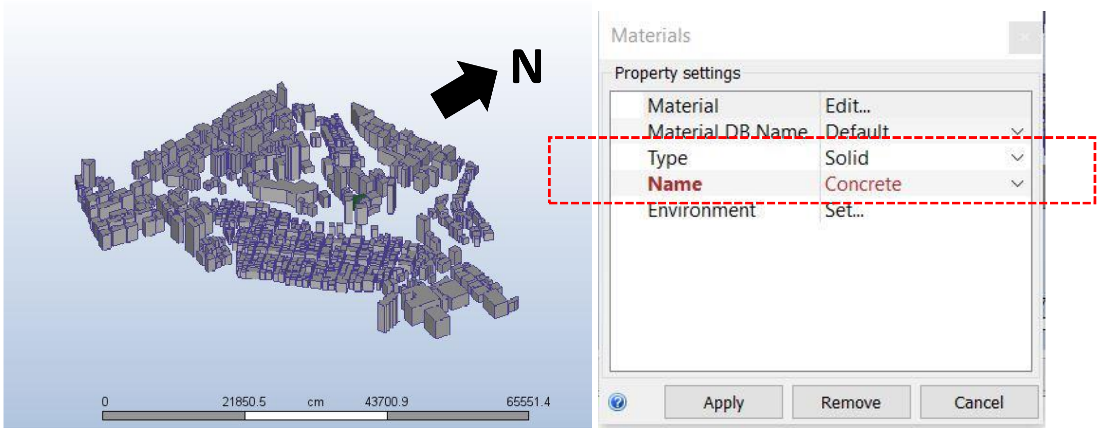


*Figure 61 - School #8: Concrete material for the base-model (prepared by: author)*

Next step is to specify the boundary conditions of the wind box, which means specifying from which surface of the box enters the wind and from which surface it comes out. To simplify this, basically consider the wind box as a wind tunnel, in which we inject a certain amount of air flow and just note the results of its impact on the model.

Therefore, the surface or the edge of the box from which the wind enters, is the direction of the dominant wind, it is assigned as velocity and is given a specific magnitude (m/s). As for the opposing surface or edge of the box, it is assigned as pressure and is given a magnitude of zero in order for the wind flow simulation to work correctly.

Since we have different wind directions and speeds according to the wind roses (figures 52-54), and therefore we have oriented the wind box in three different orientations as explained previously, the boundary conditions are different for each file. In the following sub-sections, each wind direction is explained separately.

*4.4.1.4.a. School #8: Boundary Conditions specifications (annual wind flow)*

As mentioned before, the annual wind flow of the dominant wind or prevailing wind is from the South-East. Accordingly the wind box is oriented towards South-East (figure 55). Therefore, figure 62 shows that the surface towards the South-East is assigned as 'velocity' and is given a magnitude of 5.1 m/s. This specific magnitude is found from the wind rose in figure 52. Note that the rule set here for this study is that the minimum velocity or speed is to be considered for the analysis.

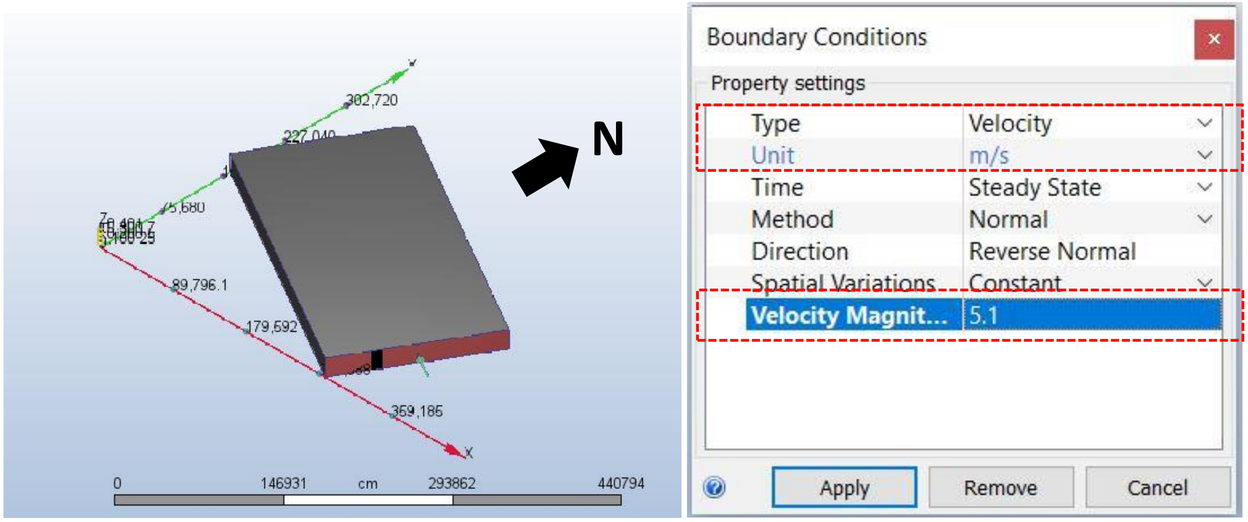



*Figure 62 - School #8: Velocity 5.1 m/s (prepared by: author)*

Figure 63 shows that the surface towards the South-West, opposing the South-East, is assigned as ‘pressure’ and is given a magnitude of zero.

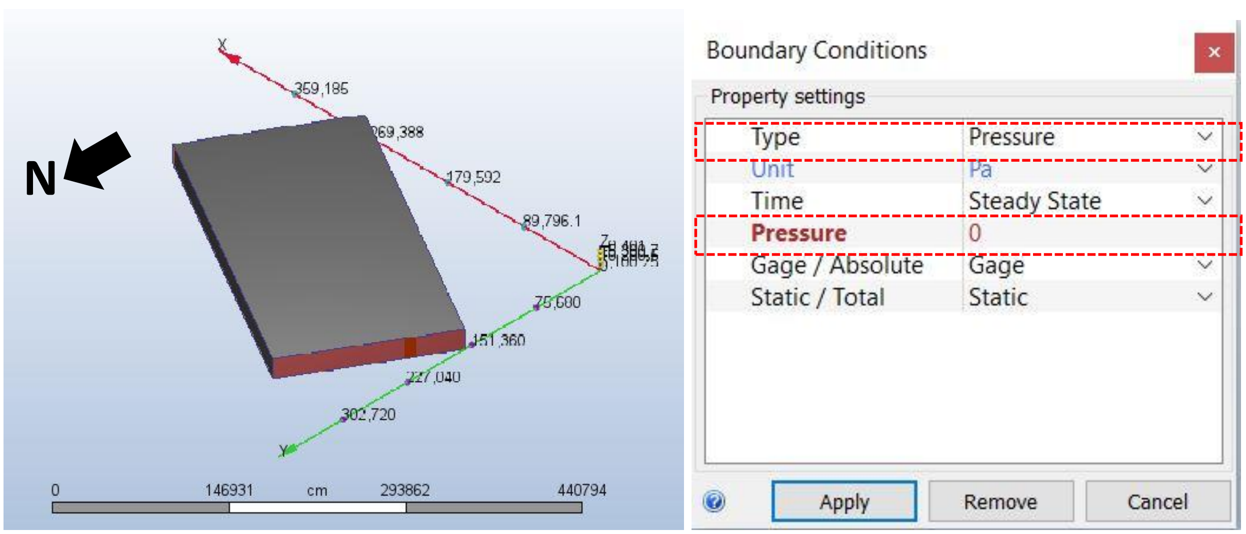



*Figure 63 - School #8: Pressure zero (prepared by: author)*

*4.4.1.4.b. School #8: Boundary Conditions specifications (winter wind flow)*

As mentioned before, the winter wind flow of the dominant wind or prevailing wind is from the South-West. Accordingly the wind box is oriented towards South-West (figure 56). Therefore, figure 64 shows that the surface towards the South-West is assigned as ‘velocity’ and is given a magnitude of 8.5 m/s. This specific magnitude is found from the wind rose in figure 53. Note that the rule set here for this study is that the minimum velocity or speed is to be considered for the analysis.

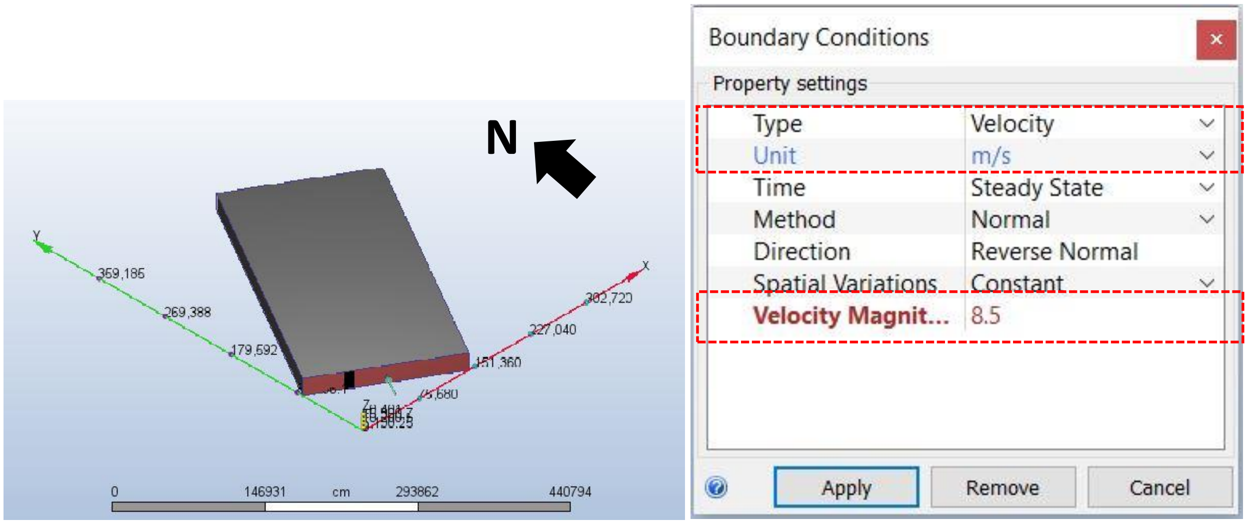



*Figure 64 - School #8: Velocity 8.5 m/s (prepared by: author)*

Figure 65 shows that the surface towards the South-East, opposing the South-West, is assigned as 'pressure' and is given a magnitude of zero.

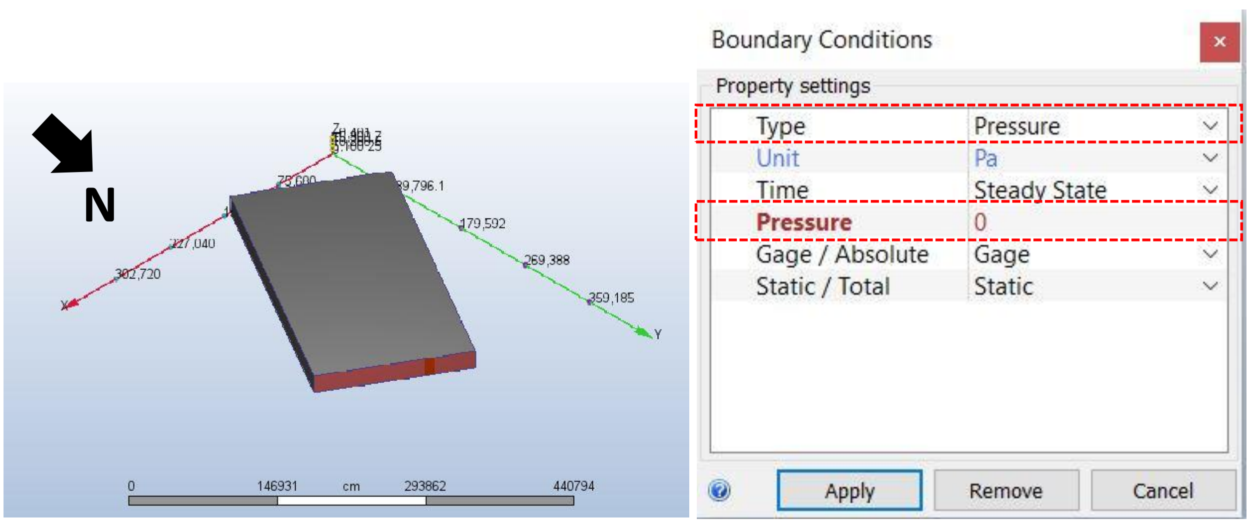



*Figure 65 - School #8: Pressure zero (prepared by: author)*

*4.4.1.4.c. School #8: Boundary Conditions specifications (summer wind flow)*

As mentioned before, the summer wind flow of the dominant wind or prevailing wind is from the West. Accordingly the wind box is oriented towards West (figure 57). Therefore, figure 66 shows that the surface towards the West is assigned as 'velocity' and is given a magnitude of 5.1 m/s.

This specific magnitude is found from the wind rose in figure 54. Note that the rule set here for this study is that the minimum velocity or speed is to be considered for the analysis.

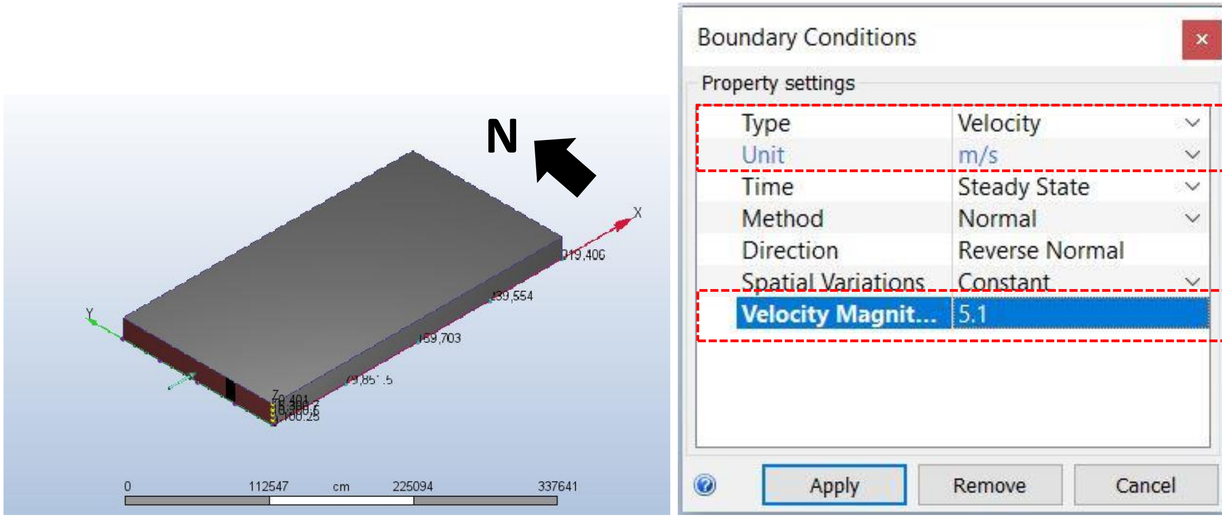



*Figure 66 - School #8: Velocity 5.1 m/s (prepared by: author)*

Figure 67 shows that the surface towards the East, opposing the West, is assigned as 'pressure' and is given a magnitude of zero.

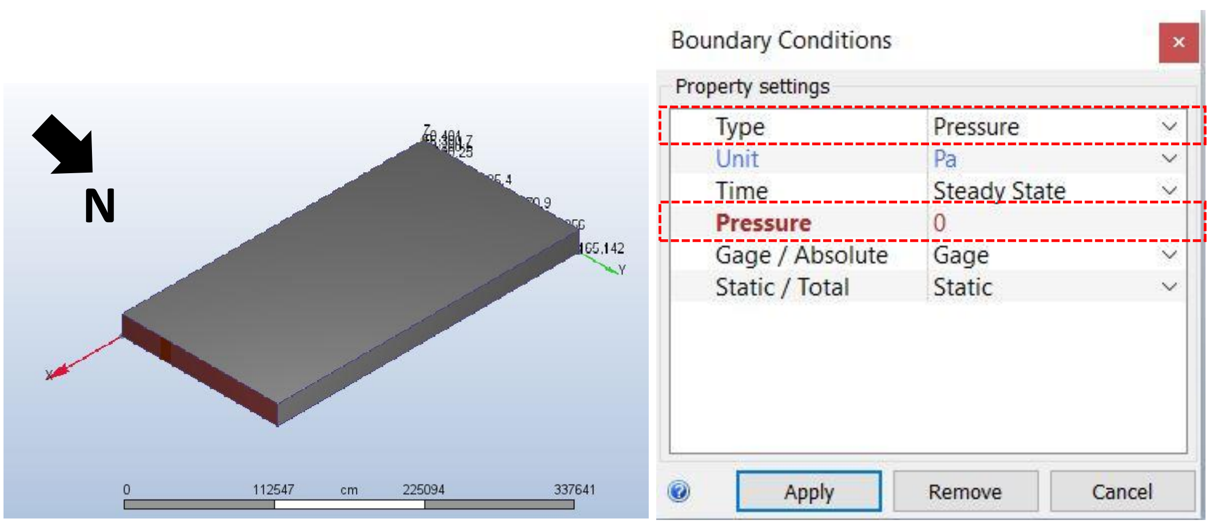



*Figure 67 - School #8: Pressure zero (prepared by: author)*

After specifying the boundary conditions of each orientation, the following step is for the mesh sizing (figure 59). Simply we press the ‘autosize’ button, and the software automatically creates the mesh of the model and resizes it in order to scale the wind flow to the 3D model. (Figure 68)

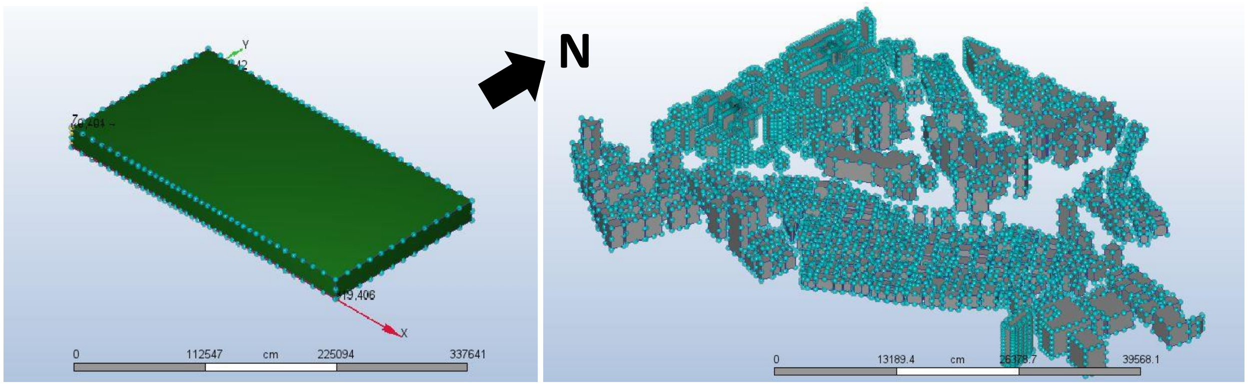


*Figure 68 - School #8: Meshing Autosize (prepared by: author)*

The final step is to solve (figure 59). The results of each analysis are shown separately in the following sub-sections.

*4.4.1.5. Analysis Results*

*4.4.1.5.a. Annual Wind Flow*

After clicking ‘solve’ in CFD, the software automatically generates a wind simulation based on all the criteria that we have given, such as the wind direction and speed or velocity. Therefore, the simulation starts appearing as a graph composed of ‘iterations’ which means steps, showing the wind velocity divided on the three axes x, y and z (which means in 3D mode or reality). As shown in figure 69, each criteria is represented by a line of different color on the graph. What interests us for this study is the first three lines Vx, Vy and Vz. The more these three lines are converging at the end of the graph, which means at the end of the simulation or analysis process, the more accurate the analysis is. Consequently, better results are generated, that are closer to reality.

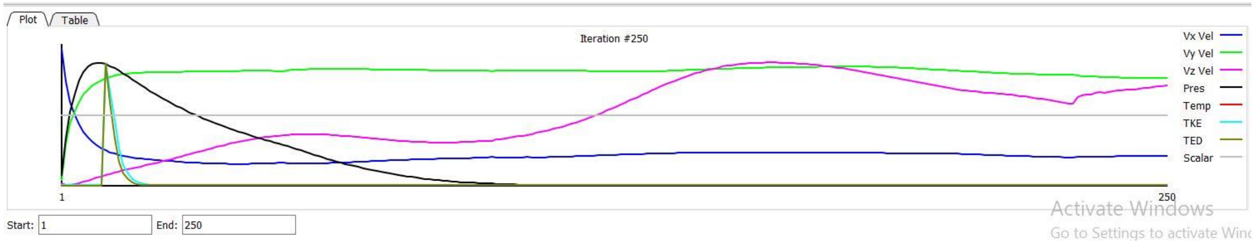



*Figure 69 - School #8: Analysis Graph (Annual) (prepared by: author)*

Figure 70 shows the wind simulation on school #8, on annual basis, which means around the year. The wind is flowing from South-East to South-West, as explained before in the previous sub-sections. The wind velocity or speed is 5.1 m/s, and it is minimized to 3 m/s in the below figure, in order to have a more legible simulation.

In this step we add a plane to obtain the results of the wind at the level of the school's rooftop, where the crops will be placed.

The plane is placed according to:

X=0, Y=0, and Z=1.

Meaning that this plane represents the wind flow on the horizontal level of the building's rooftop. The legend is in meter per second (m/s) and ranges from 0 to 3 m/s, showing the velocity or the speed of the wind. The vectors show the direction or the flow of the wind. As we can see in this simulation result, the velocity of the wind around the school's building on this level varies from 0 to 1.8 m/s, following the legend and its indicated colors. (Figure 70)

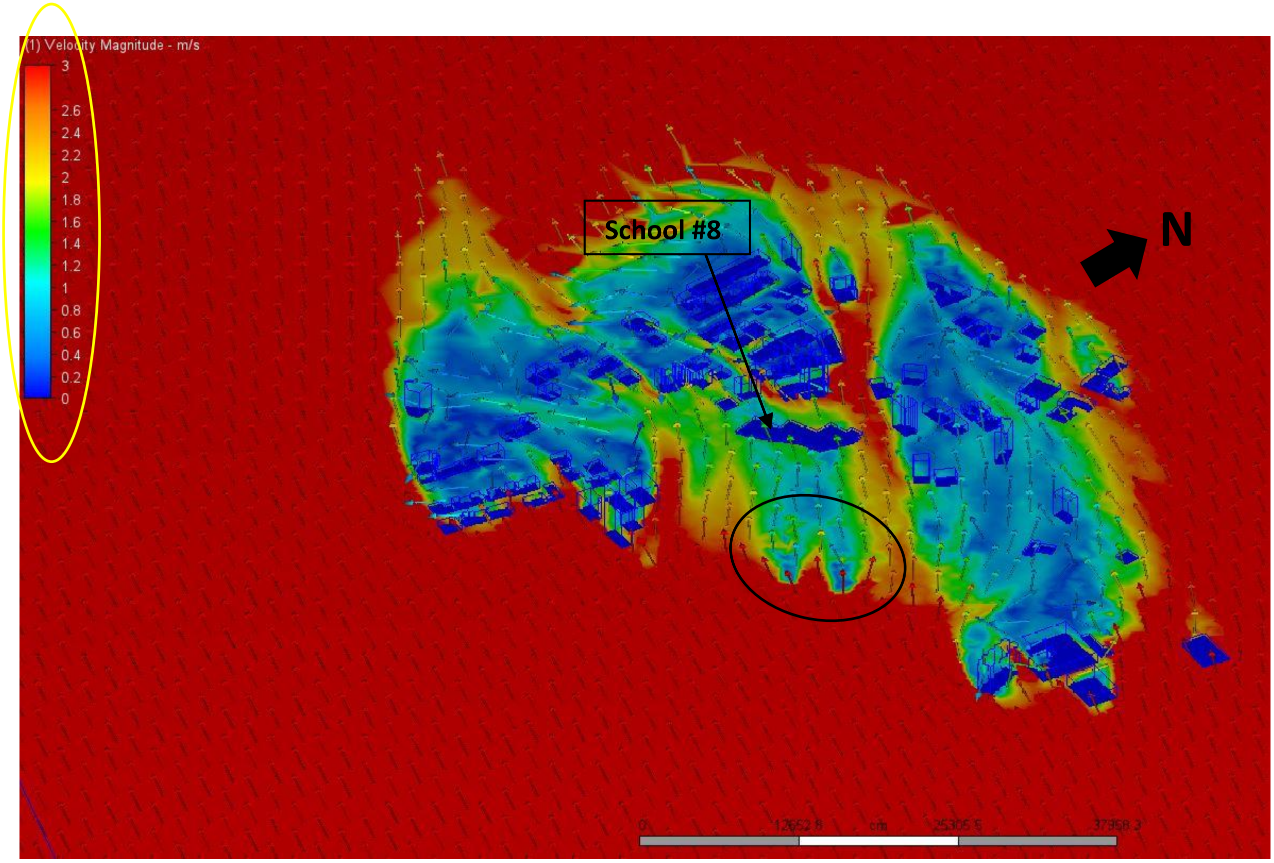



*Figure 70 - School #8: Wind Simulation (Annual) (prepared by: author)*

As we see in figure 70, the wind flows freely from the South-East towards the school's building, with a velocity of 3+ m/s. However, the wind is blocked by two buildings facing the school, highlighted with a black circle in the above figure, resulting in a breakage in its flow and a decrease in its velocity or speed. Which means, the wind arrives at a lower speed from its normal one to the school's rooftop.

### *4.4.1.5.b. Winter Wind Flow*

After clicking 'solve' in CFD, the software automatically generates a wind simulation based on all the criteria that we have given, such as the wind direction and speed or velocity. Therefore, the simulation starts appearing as a graph composed of 'iterations' which means steps, showing the wind velocity divided on the three axes x, y and z (which means in 3d mode or reality). As shown in figure 71, each criteria is represented by a line of different color on the graph. What interests us for this study is the first three lines Vx, Vy and Vz. The more these three lines are converging at

the end of the graph, which means at the end of the simulation or analysis process, the more accurate the analysis is. Consequently, better results are generated, that are closer to reality.

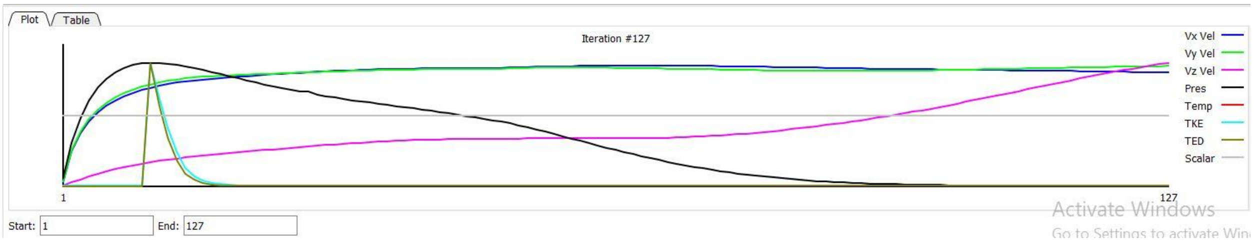



*Figure 71 - School #8: Analysis Graph (Winter) (prepared by: author)*

Figure 72 shows the wind simulation on school #8, during the winter, which means from January until March. The wind is flowing from South-West to South-East, as explained before in the previous sub-sections. The wind velocity or speed is 8.5 m/s, and it is minimized to 4 m/s in the below figure, in order to have a more legible simulation.

In this step we add a plane to obtain the results of the wind at the level of the school's rooftop, where the crops will be placed.

The plane is placed according to:

X=0, Y=0, and Z=1.

Meaning that this plane represents the wind flow on the horizontal level of the building's rooftop. The legend is in meter per second (m/s) and ranges from 0 to 4 m/s, showing the velocity or the speed of the wind. The vectors show the direction or the flow of the wind. As we can see in this simulation result, the velocity of the wind around the school's building on this level varies from 0 to 4 m/s, following the legend and its indicated colors. (Figure 72)

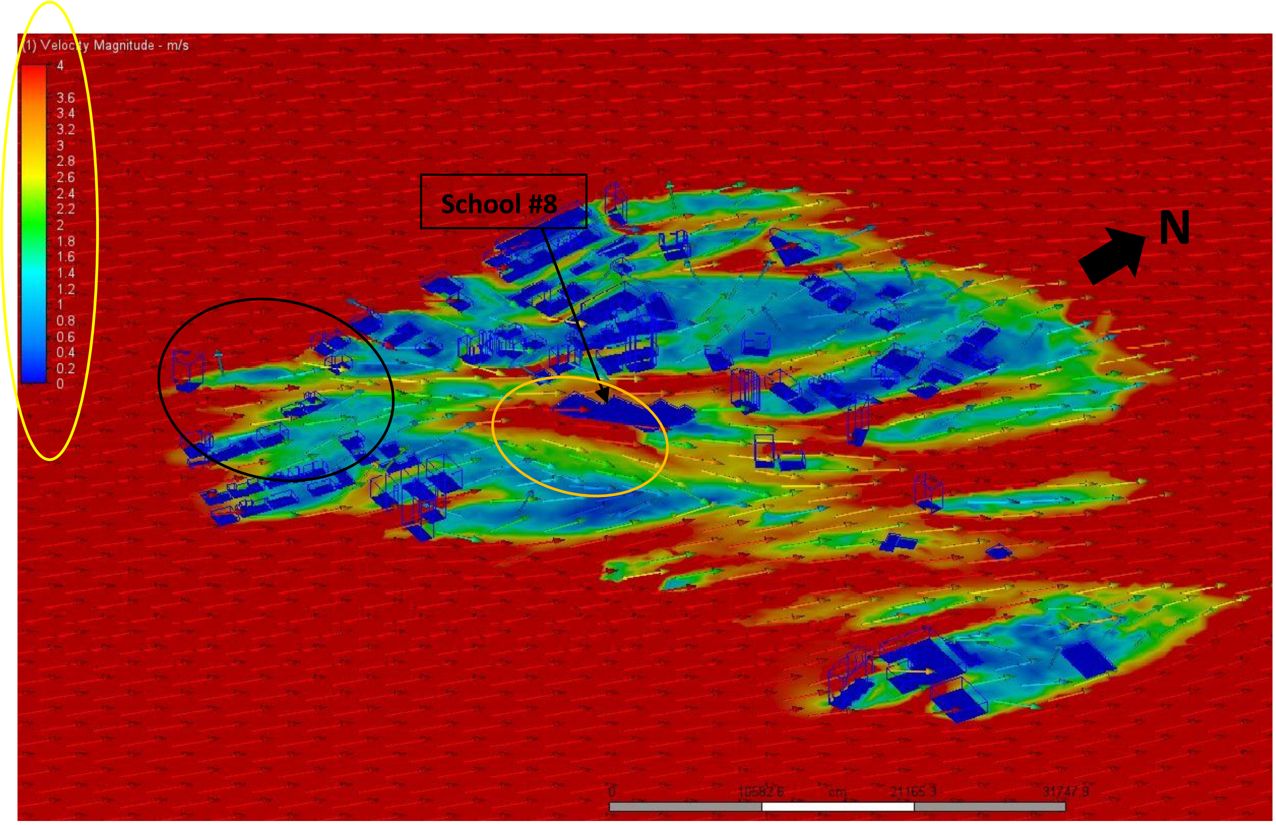


*Figure 72 - School #8: Wind Simulation (Winter) (prepared by: author)*

As we see in figure 72, the wind flows freely from the South-West towards the school's building, with a velocity of 4+ m/s. However, the wind is blocked by several buildings facing the school, highlighted with a black circle in the above figure, resulting in a breakage in its flow and a decrease in its velocity or speed. Which means, the wind arrives at a lower speed from its normal one to the school's rooftop from one edge. Moreover, from another edge, highlighted in an orange circle, the wind picks up its speed or velocity so it reaches its maximum, due to the fact that there are no buildings there to block the wind flow.

*4.4.1.5.c. Summer Wind Flow*

After clicking 'solve' in CFD, the software automatically generates a wind simulation based on all the criteria that we have given, such as the wind direction and speed or velocity. Therefore, the simulation starts appearing as a graph composed of 'iterations' which means steps, showing the wind velocity divided on the three axes x, y and z (which means in 3d mode or reality). As shown in figure 73, each criteria is represented by a line of different color on the graph. What interests us for this study is the first three lines Vx, Vy and Vz. The more these three lines are converging at

the end of the graph, which means at the end of the simulation or analysis process, the more accurate the analysis is. Consequently, better results are generated, that are closer to reality.

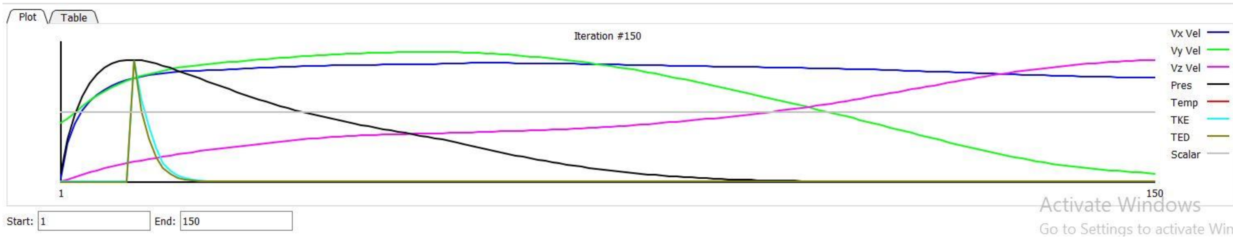



*Figure 73 - School #8: Analysis Graph (Summer) (prepared by: author)*

Figure 74 shows the wind simulation on school #8, during the summer, which means from July until September. The wind is flowing from South-West to South-East, as explained before in the previous sub-sections. The wind velocity or speed is 5.1 m/s, and it is minimized to 3 m/s in the below figure, in order to have a more legible simulation.

In this step we add a plane to obtain the results of the wind at the level of the school's rooftop, where the crops will be placed.

The plane is placed according to:

X=0, Y=0, and Z=1.

Meaning that this plane represents the wind flow on the horizontal level of the building's rooftop. The legend is in meter per second (m/s) and ranges from 0 to 3 m/s, showing the velocity or the speed of the wind. The vectors show the direction or the flow of the wind. As we can see in this simulation result, the velocity of the wind around the school's building on this level varies from 0 to 1 m/s, following the legend and its indicated colors. (Figure 74)

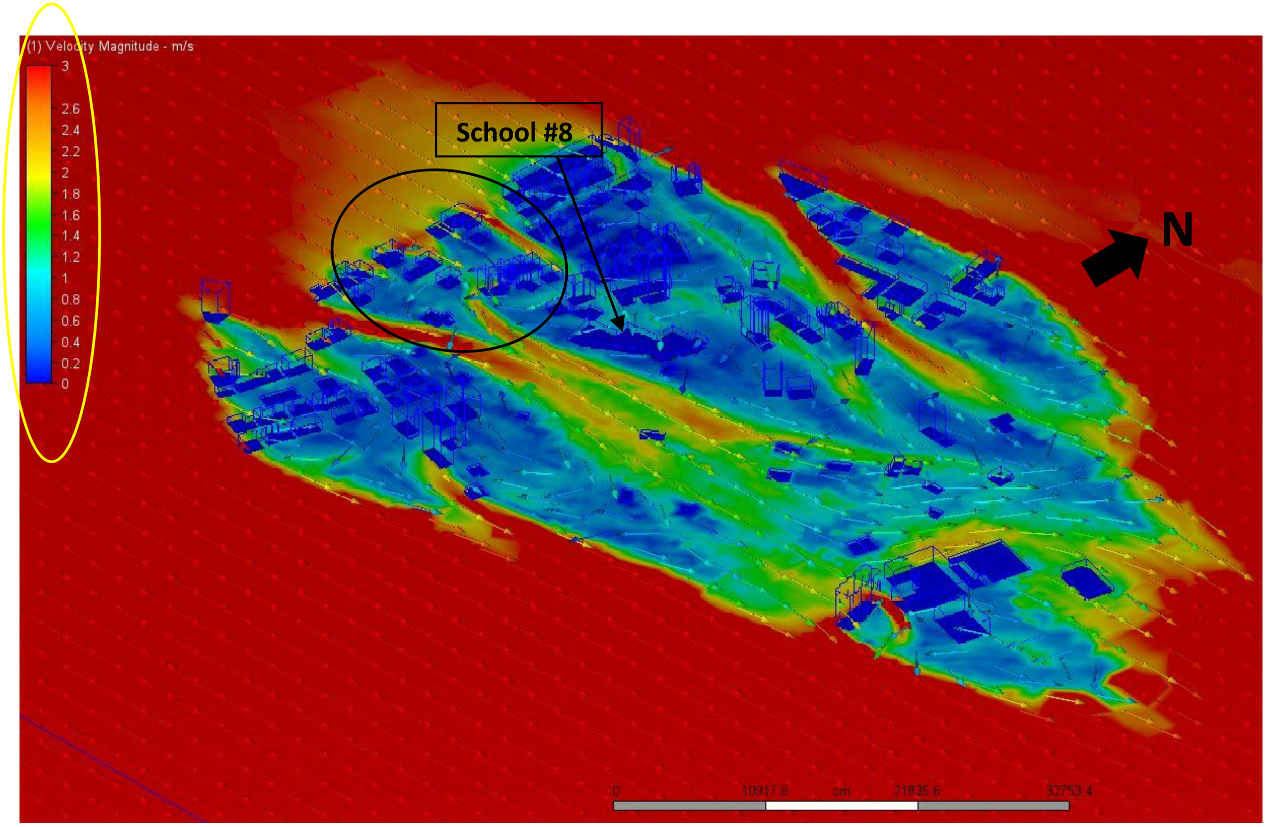



*Figure 74 - School #8: Wind Simulation (Summer) (prepared by: author)*

As we see in figure 74, the wind flows freely from the West towards the school's building, with a velocity of 3+ m/s. However, the wind is blocked by several buildings facing the school, highlighted with a black circle in the above figure, resulting in a breakage in its flow and a decrease in its velocity or speed. Which means, the wind arrives at a lower speed from its normal one to the school's rooftop from one edge.

### *4.4.1.6. Comparison of the results for School #8*

After running three simulations for the wind flow (annual, winter and summer) and reading all the results generated from the analysis of the wind flow around School #8 rooftop, we are able to perceive the differences in the wind direction, speed and breakage around the mentioned building. These differences are due to the context, which means the neighboring buildings and their specifications, such as their height and location in comparison with the height and location of the school's building.

Around the year, the wind flows from the South-East mainly, that is what we call the dominant wind or prevailing wind, with a velocity or speed of 5.1 m/s. The wind reaches the school's rooftop at a maximum velocity of 1.8 m/s, due to the two buildings facing the school, that are higher from the school's building by one level. This results in a slight breakage in the wind flow.

During the winter (from January until March), the wind flows from the South-West mainly, that is what we call the dominant wind or prevailing wind, with a velocity or speed of 8.5 m/s. The wind reaches the school's rooftop at a minimum velocity of 4 m/s, due to the absence of any building facing the school.

During the summer (from July until September), the wind flows from the West mainly, that is what we call the dominant wind or prevailing wind, with a velocity or speed of 5.1 m/s. The wind reaches the school's rooftop at a maximum velocity of 1 m/s, due to the several buildings facing the school, that are higher from the school's building by at least two levels. This results in a breakage in the wind flow.

Below is table 18, showing the results compared together, for a better reading.

| | **Wind flow direction** | **Normal Velocity (m/s)** | **Minimum Velocity around the Rooftop (m/s)** | **Maximum Velocity around the Rooftop (m/s)** | **Breakage of wind flow** | **Reason of breakage** |
|---|---|---|---|---|---|---|
| **Annual** | South-East | 5.1 | 1 | 1.8 | Yes | Two facing buildings |
| **Winter (January until March)** | South-West | 8.5 | 4 | 8.5 | No | - |
| **Summer (July until September)** | West | 5.1 | 0 | 1 | Yes | Several facing buildings |

*Table 18 - School #8: Comparison of simulation results (annual, winter. summer) (prepared by: author)*

*4.4.2. School #50: analysis process (From Revit to CFD)*

*4.4.2.1. Base-model and Location*

As mentioned before, School #50, *Ras Beirut Mixed Public School or Jaber Ahmad Al Sabah Public School* is located in Ras Beirut district, under the coordinates 33.896252; 35.47353 (data extracted from the sheet provided by the UNICEF as mentioned before in Chapter 3). This location is easily found by copying and pasting the coordinates into Google Maps.

The base-model is extracted from the 3D model (Rhino file as mentioned in Chapter 3) of Municipal Beirut; it is basically the mentioned school's building in the center along with its neighboring buildings around it to represent the context which can either block or let the wind flow easily around the school's building and in particular the building's rooftop. Note that the model is simplified in order to have better results in CFD software, which means, all the buildings are on the same level so the topography is deleted, the roads are also deleted. (Figure 75)

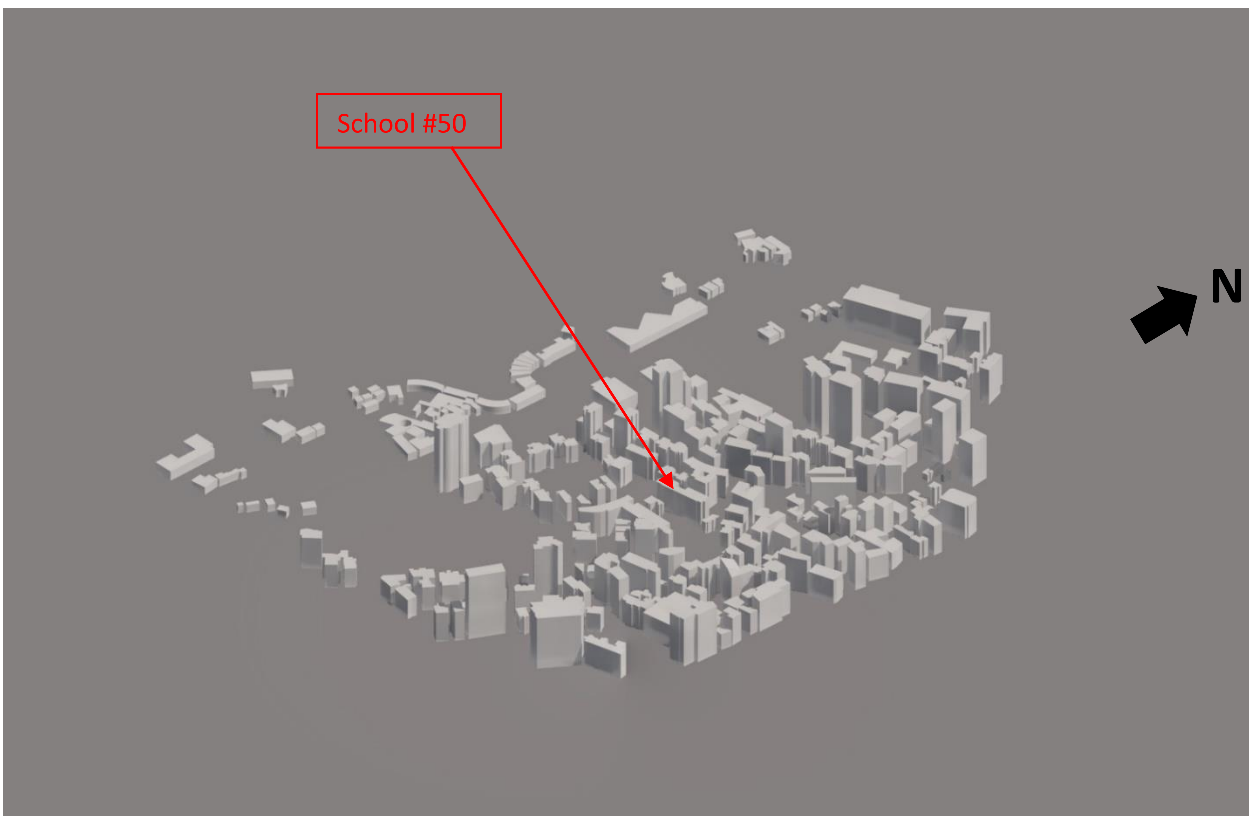



*Figure 75 - School 50 with context 3D model (prepared by: author)*

After the base-model is drawn in Revit, the location is set following the same coordinates used to find the location of the school on Google Maps, and a weather station is also specified, having approximately the same altitude and climate as the school's location (figure 76). The weather station will give climate specifications of this particular location such as the wind flow, direction and velocity. Note that the weather station chosen here is in the one in the middle of the Mediterranean Sea, facing the shore, because it will give more accurate specifications of the climate around the location of school #50, due to the fact of its closeness to the shore and that it is exposed to the Mediterranean wind.

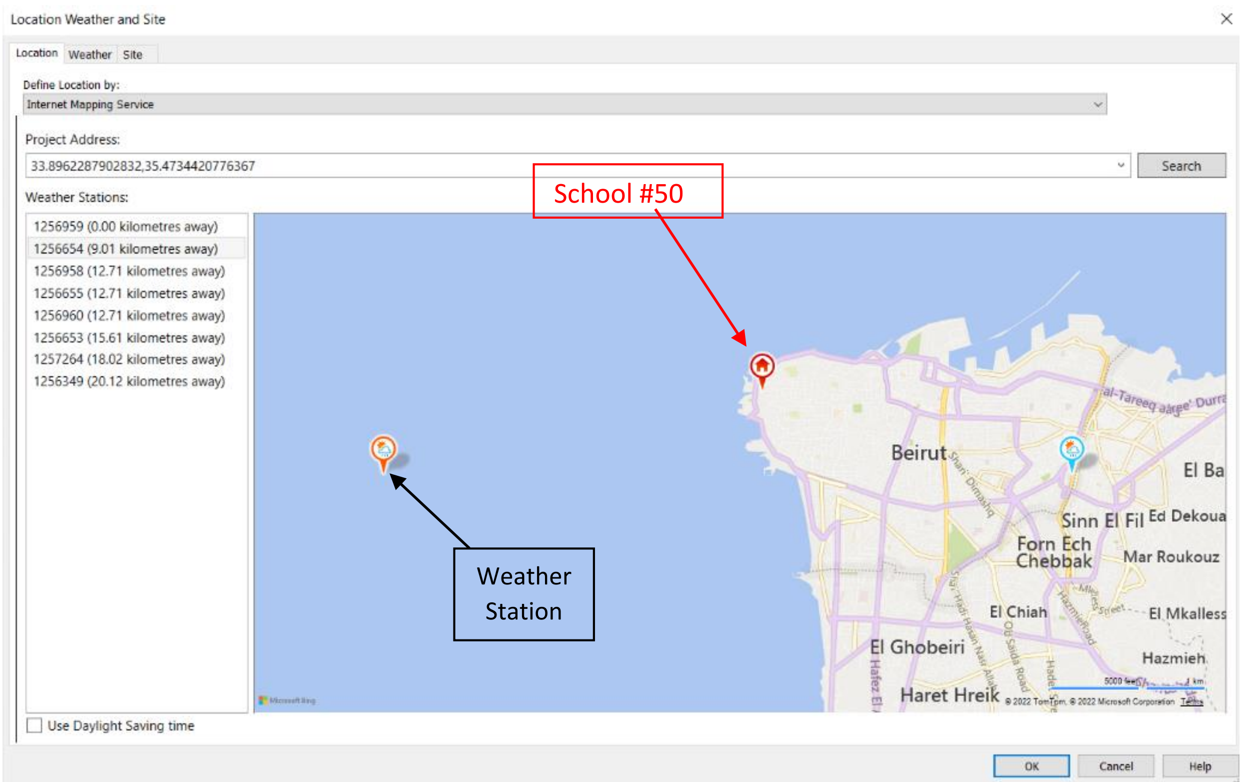



*Figure 76 - School #50 Location and Weather Station (prepared by: author)*

### *4.4.2.2. Energy Model / Insight 360 / Wind Rose*

After drawing the base-model in Revit and specifying the location and weather station, we have to create an 'energy model' of the base-model and optimize it (figure 77) in order for the project to be registered in Insight 360, and therefore in GBS (Green Building Studio) where the wind rose will be available (figures 78-80). These steps are standard for this process of wind simulation of any project, either architectural or urban.

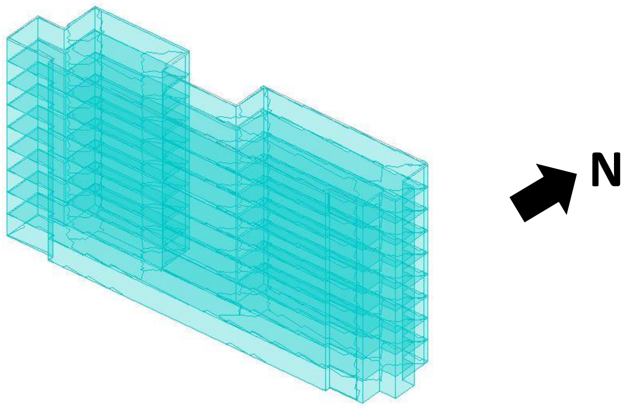



*Figure 77 - School #50: energy model (prepared by: author)*

In GBS, the specifications of the weather station that is determined are shown in different graphs, such as temperature, humidity, sky coverage, dry bulb, wind speed and direction and various other climate characteristics specific to the location. This study focuses on the wind flow research around the school's building and rooftop, therefore, only the wind roses are studied and looked at from all these characteristics.

Figure 78 shows the wind rose of this specific location on annual basis, which means the wind direction and velocity or speed around the year. As shown in the figure, the prevailing wind or dominant wind is from South, with a velocity of 8.5-11 m/s.

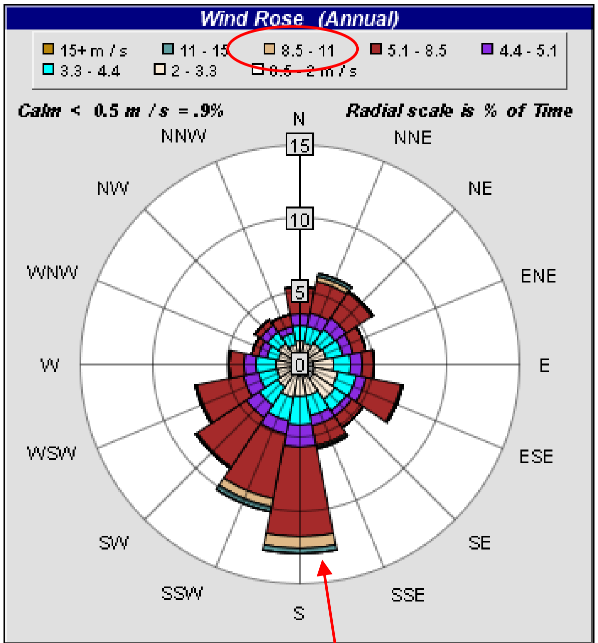



*Figure 78 - School #50: Wind Rose (annual) (extracted from: gbs.autodesk.com; prepared by: author)*

Figure 79 shows the wind rose of this specific location in winter, which means the wind direction and velocity or speed from January until March. As shown in the figure, the prevailing wind or dominant wind is from South, with a velocity of 11-15 m/s.

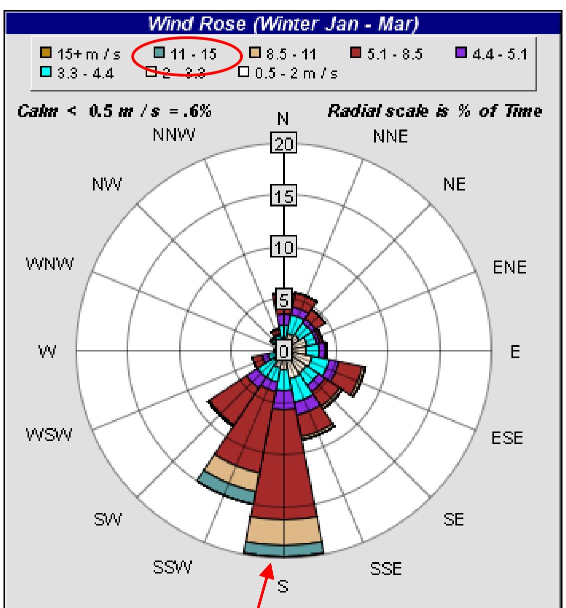



*Figure 79 - School #50: Wind rose (winter) (extracted from: gbs.autodesk.com; prepared by: author)*

Figure 80 shows the wind rose of this specific location in summer, which means the wind direction and velocity or speed from July until September. As shown in the figure, the prevailing wind or dominant wind is from South-West, with a velocity of 5.1-8.5 m/s.

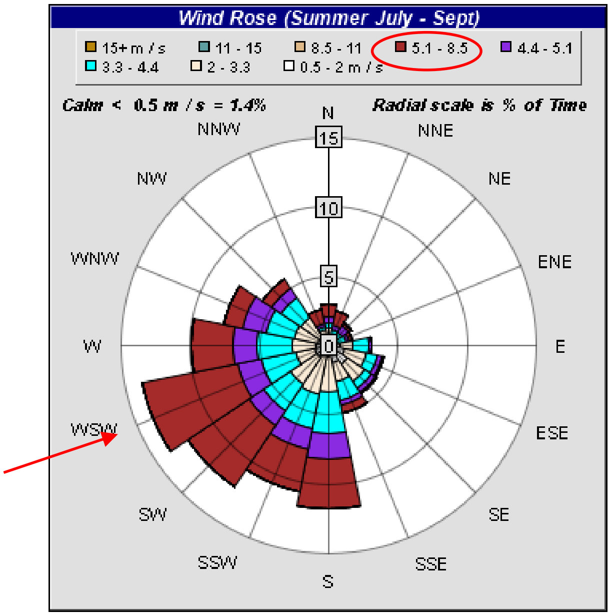



*Figure 80 - School #50: Wind rose (summer) (extracted from: gbs.autodesk.com; prepared by: author)*

### *4.4.2.3. Wind Box in Revit*

After understanding the wind direction and speed in this specific location, a box is drawn in Revit around the base-model, representing the 'wind box' or 'wind tunnel' in which the simulation of the wind flow will take place in CFD. In order to have an accurate simulation, the wind box is oriented following the direction of the prevailing wind or the dominant wind found from the wind rose in the previous sub-section.

Figure 81 shows the orientation of the wind box towards the South, according to the wind rose in figure 78, which is the annual wind flow. The orientation of the box is done according to a rotation of zero degree angle, as shown in the figure below.

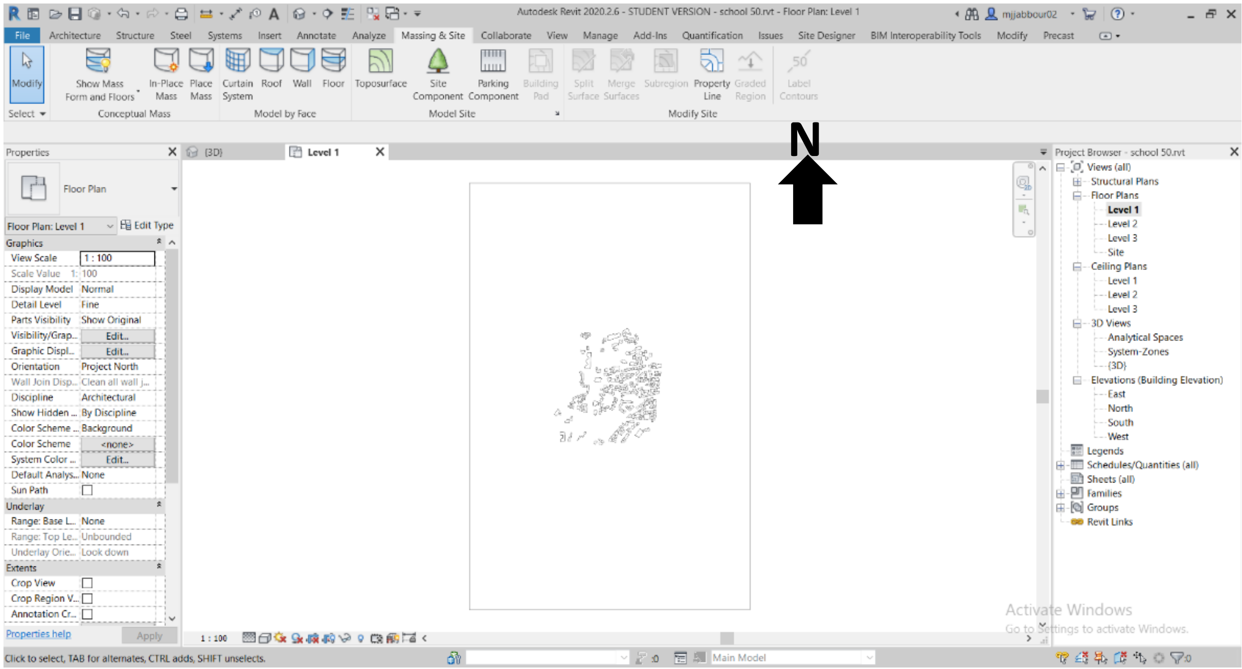



*Figure 81 - School #50: Orienting the wind box towards South (prepared by: author)*

Figure 82 shows the orientation of the wind box towards the South, according to the wind rose in figure 79, which is the wind flow during winter. The orientation of the box is done according to a rotation of zero degree angle, as shown in the figure below.

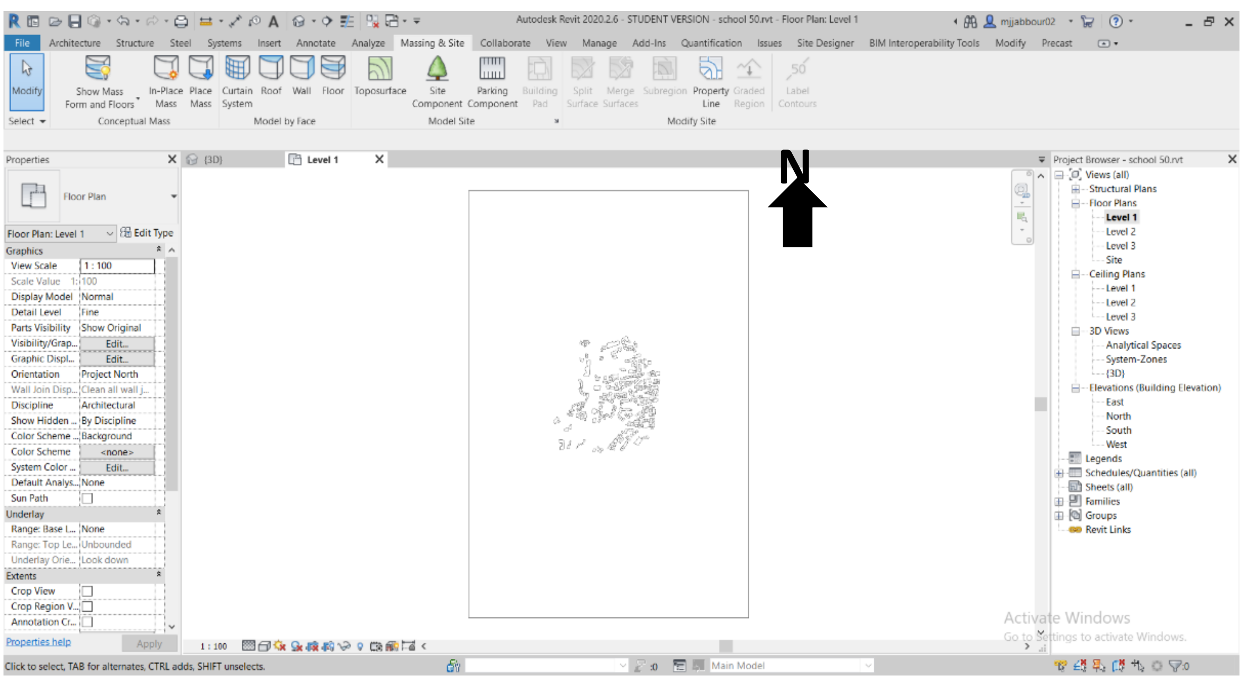



*Figure 82 - School #50: Orienting the wind box towards South (prepared by: author)*

Figure 83 shows the orientation of the wind box towards the South-West, according to the wind rose in figure 80, which is the wind flow during summer. The orientation of the box is done according to a rotation of 60 degree angle clock wise, as shown in the figure below.

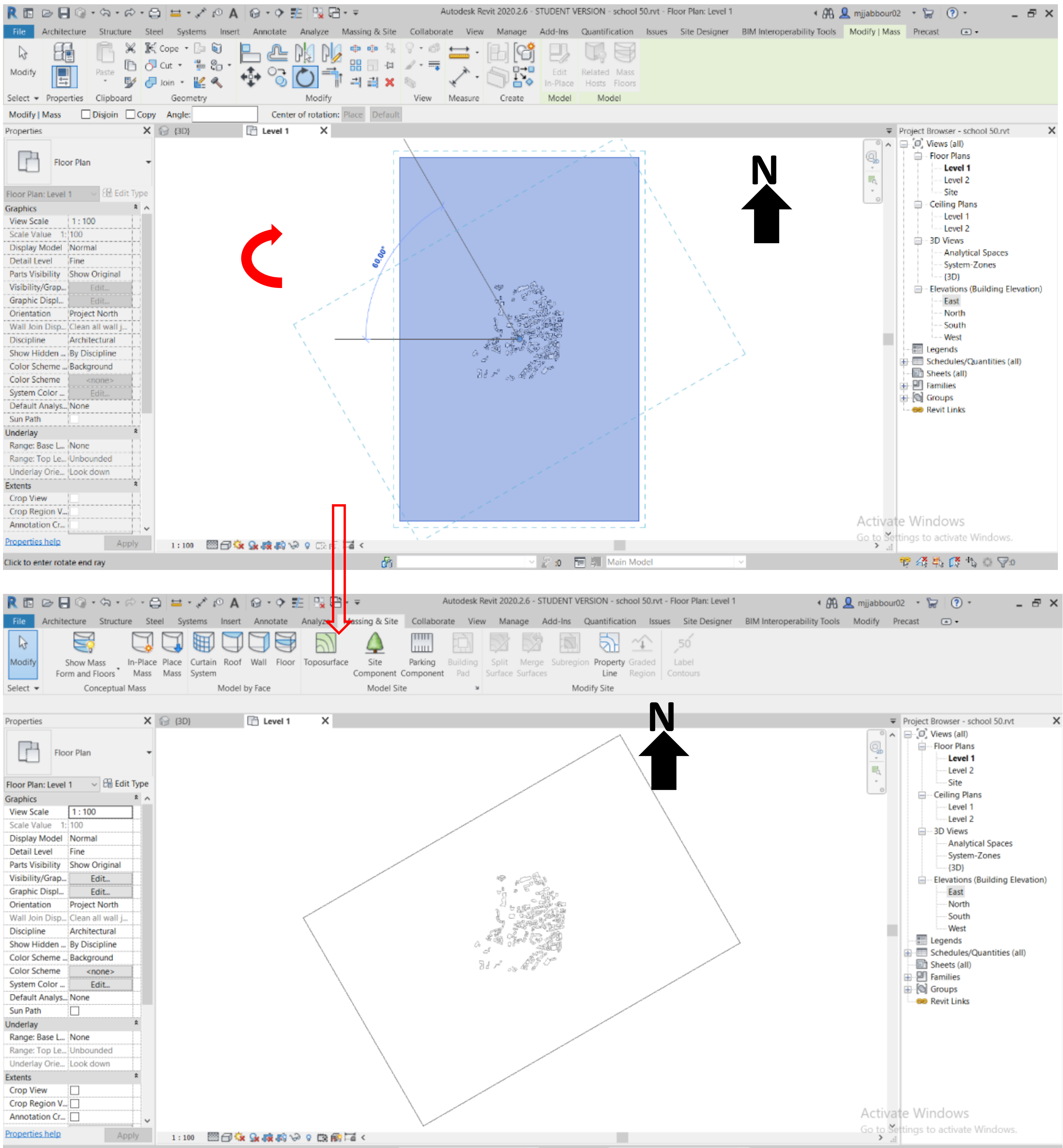



*Figure 83 - School #50: Orienting the wind box towards South-West (prepared by: author)*

*4.4.2.4. Export to CFD / Conditions specifications*

After orienting the wind box in the three different directions, each file of Revit is exported to CFD as an extension '.acis'. Then, each file is opened in CFD alone.

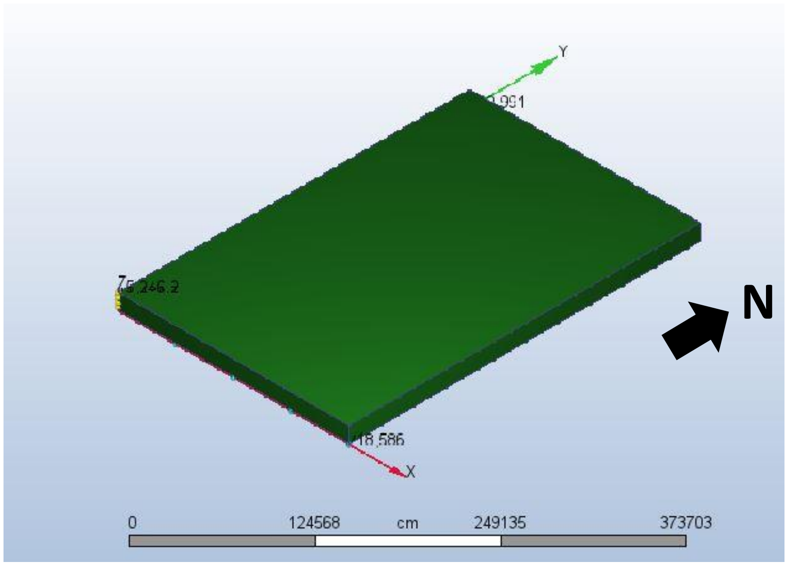



*Figure 84 - School #50: on CFD (prepared by: author)*

Figure 84 shows how the file is opened originally in CFD software. Then, we have to start specifying the conditions step by step. The steps following each other are highlighted in red in figure 85, an explained in the following.

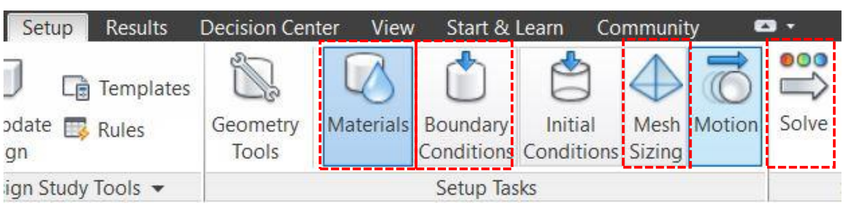



*Figure 85 - CFD Conditions (prepared by: author)*

First, we start with assigning the materials. The wind box is assigned as 'fluid' and then 'air'. (Figure 86)

And the base-model is assigned as 'solid' and then 'concrete'. (Figure 87)

Note that here the openings of the buildings are disregarded, specifically the openings of the school's building, due to the fact that this study focuses on only the rooftop of the building, therefore, the opening are not needed, what is needed for an accurate simulation is the location of the buildings according to each other.

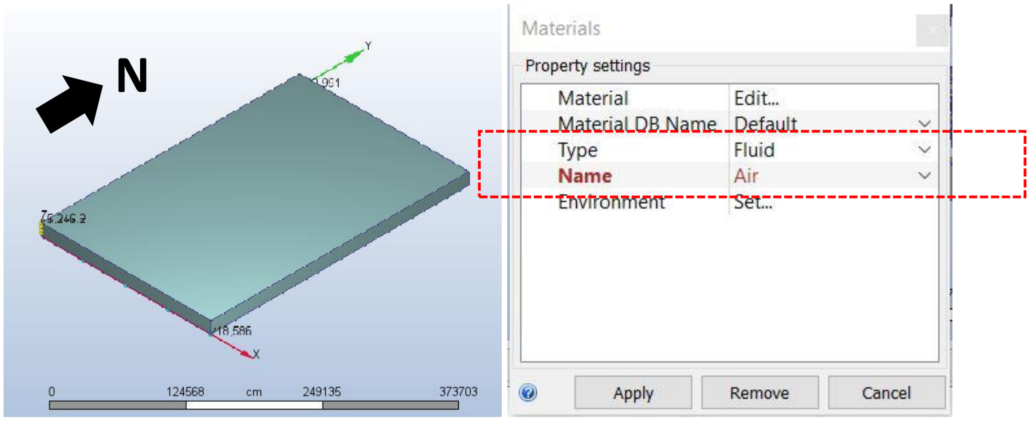



*Figure 86 - School #50: Air material for the wind box (prepared by: author)*

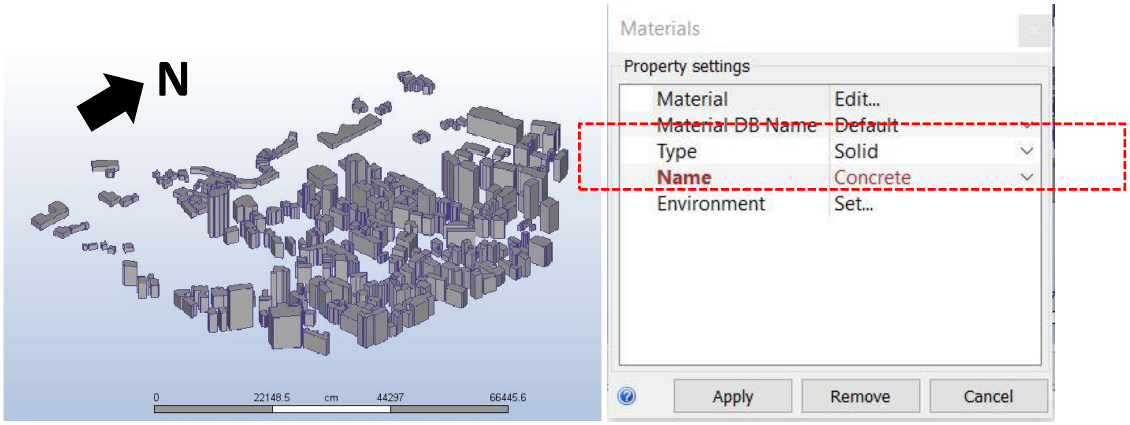



*Figure 87 - School #50: Concrete material for the base-model (prepared by: author)*

Next step is to specify the boundary conditions of the wind box, which means specifying from which surface of the box enters the wind and from which surface it comes out. To simplify this, basically consider the wind box as a wind tunnel, in which we inject a certain amount of air flow and just note the results of its impact on the model.

Therefore, the surface or the edge of the box from which the wind enters, is the direction of the dominant wind, it is assigned as velocity and is given a specific magnitude (m/s). As for the opposing surface or edge of the box, it is assigned as pressure and is given a magnitude of zero in order for the wind flow simulation to work correctly.

Since we have different wind directions and speeds according to the wind roses (figures 78-80), and therefore we have oriented the wind box in three different orientations as explained before in the previous sub-sections, the boundary conditions are different for each file. In the following sub-sections, each wind direction is explained separately.

*4.4.2.4.a. School #50: Boundary Conditions specifications (annual wind flow)*

As mentioned before, the annual wind flow of the dominant wind or prevailing wind is from the South. Accordingly the wind box is oriented towards South (figure 78). Therefore, figure 88 shows that the surface towards the South is assigned as 'velocity' and is given a magnitude of 8.5 m/s. This specific magnitude is found from the wind rose in figure 78. Note that the rule set here for this study is that the minimum velocity or speed is to be considered for the analysis.

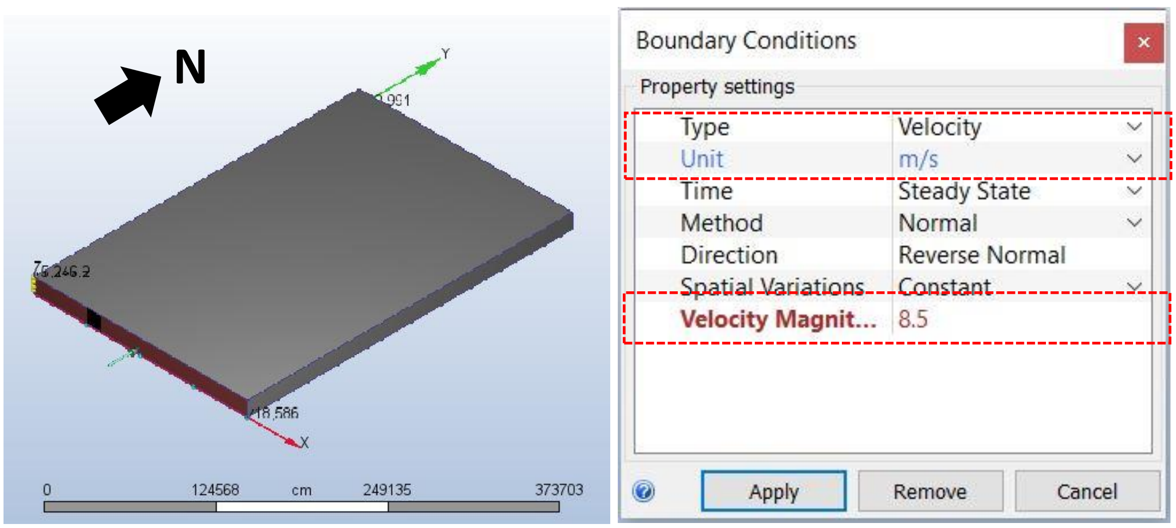



*Figure 88 - School #50: Velocity 8.5 m/s (prepared by: author)*

Figure 89 shows that the surface towards the North, opposing the South, is assigned as 'pressure' and is given a magnitude of zero.

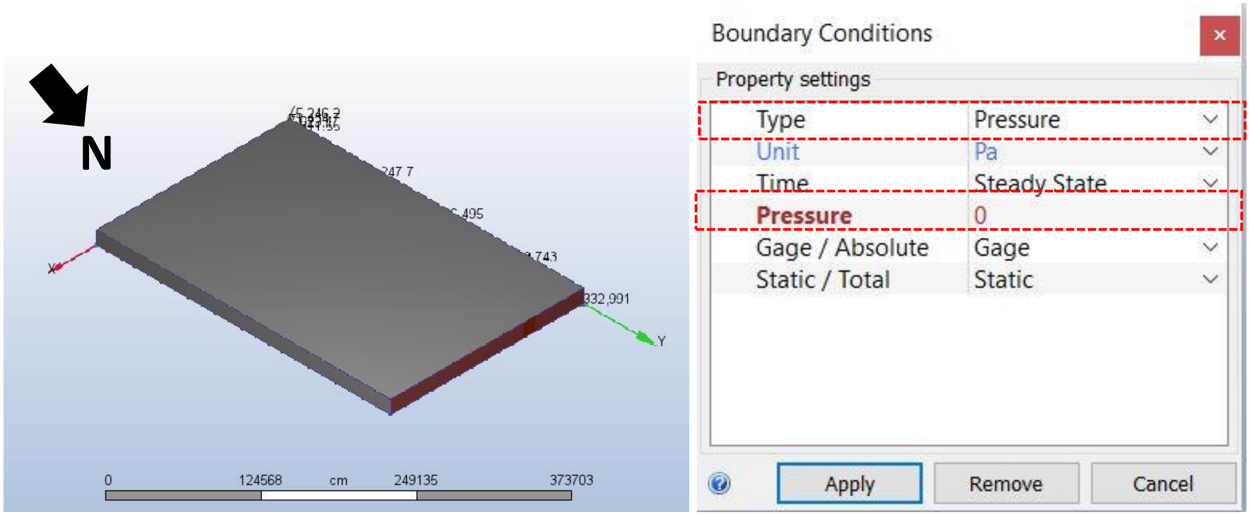



*Figure 89 - School #50: Pressure zero (prepared by: author)*

*4.4.2.4.b. School #50: Boundary Conditions specifications (winter wind flow)*

As mentioned before, the winter wind flow of the dominant wind or prevailing wind is from the South. Accordingly the wind box is oriented towards South (figure 79). Therefore, figure 90 shows that the surface towards the South is assigned as 'velocity' and is given a magnitude of 11 m/s. This specific magnitude is found from the wind rose in figure 63. Note that the rule set here for this study is that the minimum velocity or speed is to be considered for the analysis.

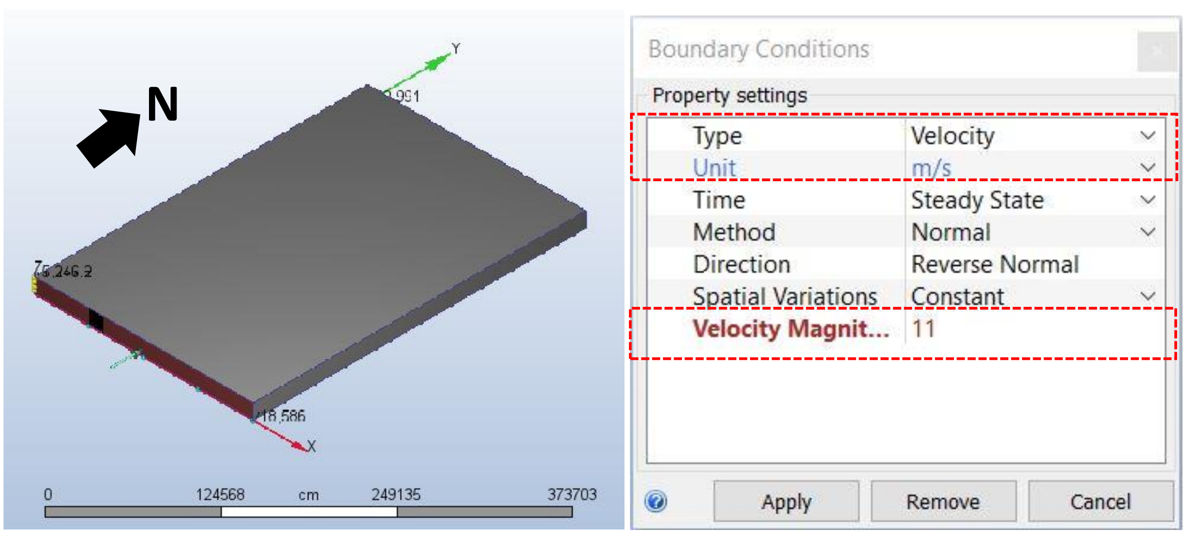



*Figure 90 - School #50: Velocity 11 m/s (prepared by: author)*

Figure 91 shows that the surface towards the North, opposing the South, is assigned as 'pressure' and is given a magnitude of zero.

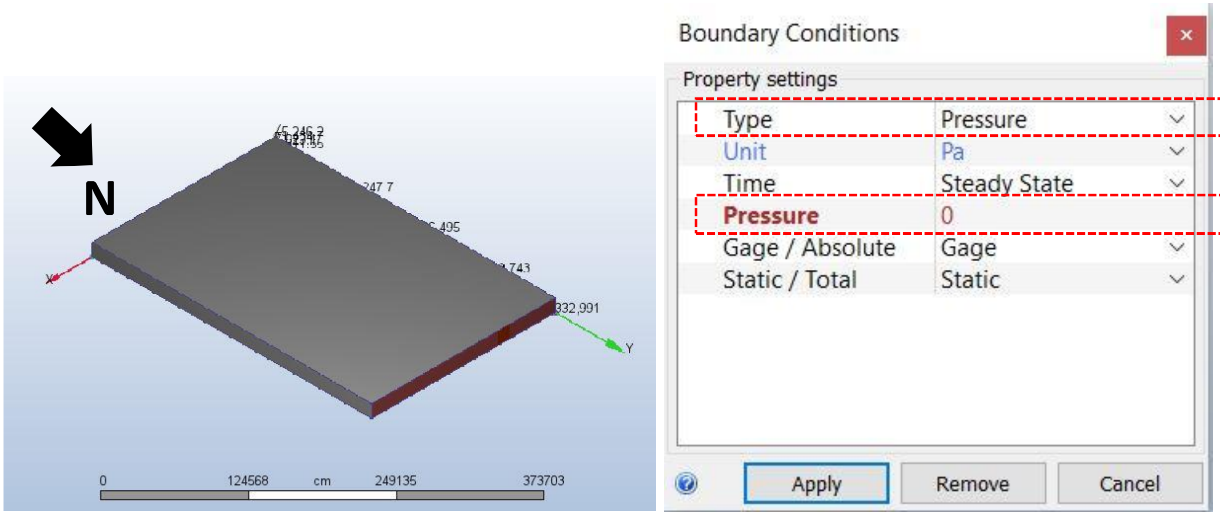



*Figure 91 - School #50: Pressure zero (prepared by: author)*

### *4.4.2.4.c. School #50: Boundary Conditions specifications (summer wind flow)*

As mentioned before, the summer wind flow of the dominant wind or prevailing wind is from the South-West. Accordingly the wind box is oriented towards South-West (figure 80). Therefore, figure 92 shows that the surface towards the South-West is assigned as 'velocity' and is given a magnitude of 5.1 m/s. This specific magnitude is found from the wind rose in figure 80. Note that the rule set here for this study is that the minimum velocity or speed is to be considered for the analysis.

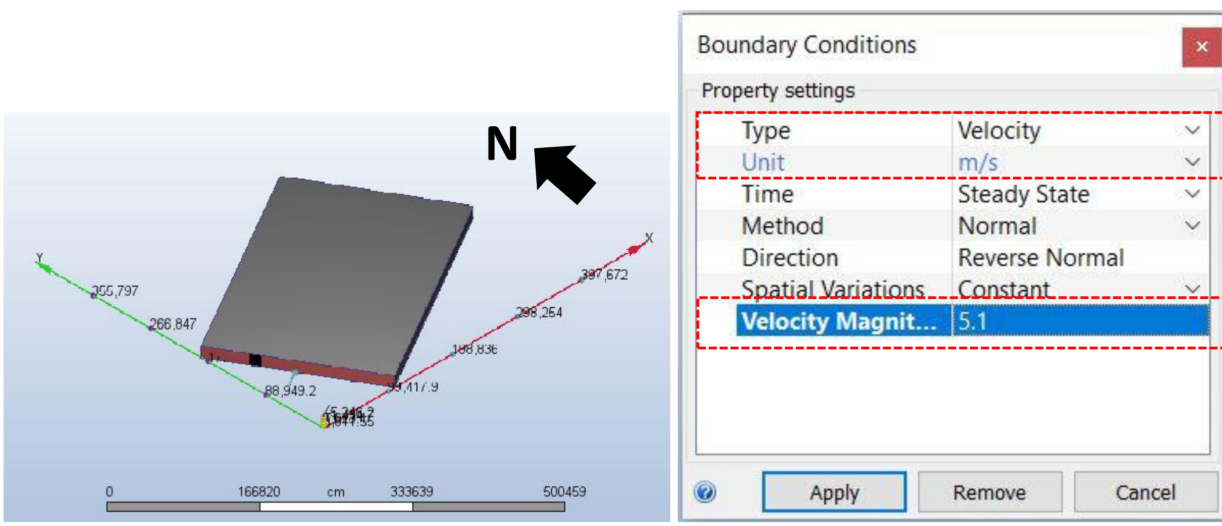



*Figure 92 - School #50: Velocity 5.1 m/s (prepared by: author)*

Figure 93 shows that the surface towards the South-East, opposing the South-West, is assigned as 'pressure' and is given a magnitude of zero.

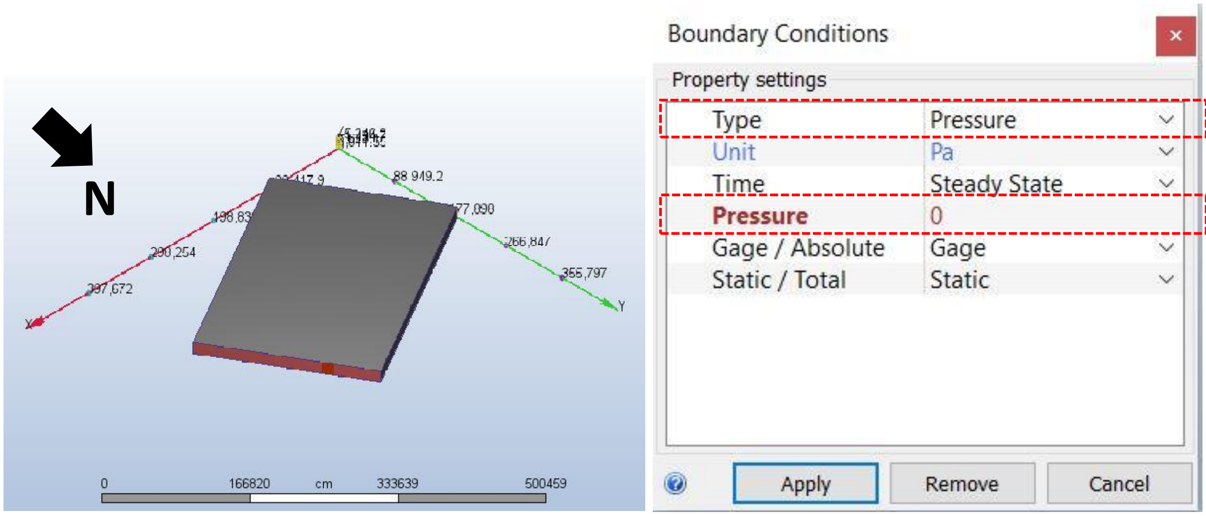



*Figure 93 - School #50: Pressure zero (prepared by: author)*

After specifying the boundary conditions of each orientation, the following step is for the mesh sizing (figure 85). Simply we press the 'autosize' button, and the software automatically creates the mesh of the model and resizes it in order to scale the wind flow to the 3D model. (Figure 94)

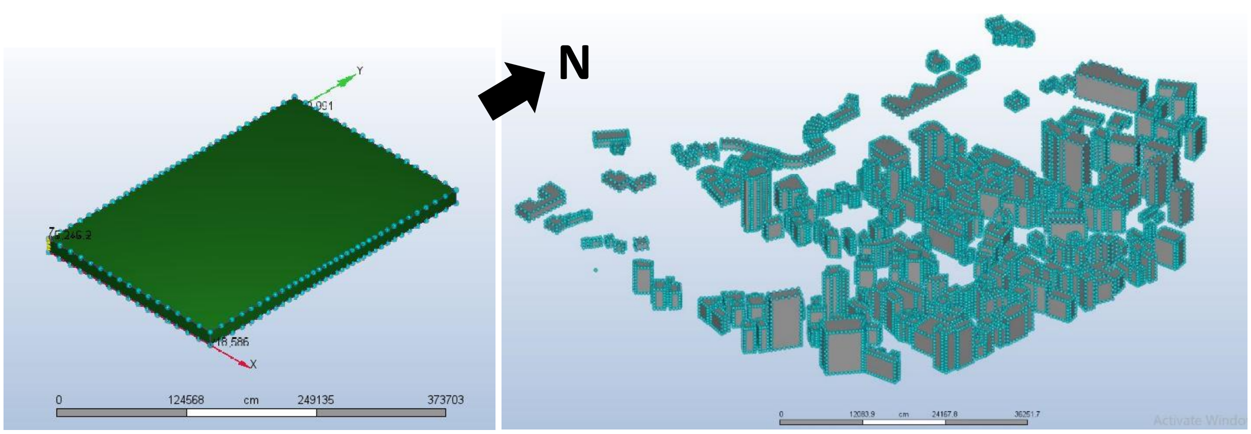



*Figure 94 - School #50: Meshing Autosize (prepared by: author)*

The final step is to solve (figure 85). The results of each analysis are shown separately in the following sub-sections.

*4.4.2.5. Analysis Results*

*4.4.2.5.a. Annual Wind Flow*

After clicking 'solve' in CFD, the software automatically generates a wind simulation based on all the criteria that we have given, such as the wind direction and speed or velocity. Therefore, the simulation starts appearing as a graph composed of 'iterations' which means steps, showing the wind velocity divided on the three axes x, y and z (which means in 3D mode or reality). As shown in figure 95, each criteria is represented by a line of different color on the graph. What interests us for this study is the first three lines Vx, Vy and Vz. The more these three lines are converging at the end of the graph, which means at the end of the simulation or analysis process, the more accurate the analysis is. Consequently, better results are generated, that are closer to reality.

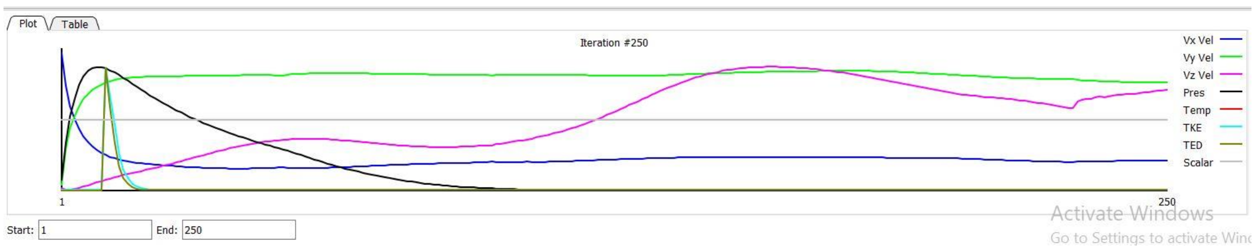



*Figure 95 - School #50: Analysis Graph (Annual) (prepared by: author)*

Figure 96 shows the wind simulation on school #50, on annual basis, which means around the year. The wind is flowing from South to North, as explained before in the previous sub-sections. The wind velocity or speed is 8.5 m/s, and it is minimized to 3 m/s in the below figure, in order to have a more legible simulation.

In this step we add a plane to obtain the results of the wind at the level of the school's rooftop, where the crops will be placed.

The plane is placed according to:

X=0, Y=0, and Z=1.

Meaning that this plane represents the wind flow on the horizontal level of the building's rooftop. The legend is in meter per second (m/s) and ranges from 0 to 3 m/s, showing the velocity or the speed of the wind. The vectors show the direction or the flow of the wind. As we can see in this simulation result, the velocity of the wind around the school's building on this level varies from 1.8 m/s to 3+ m/s, following the legend and its indicated colors. (Figure 96)

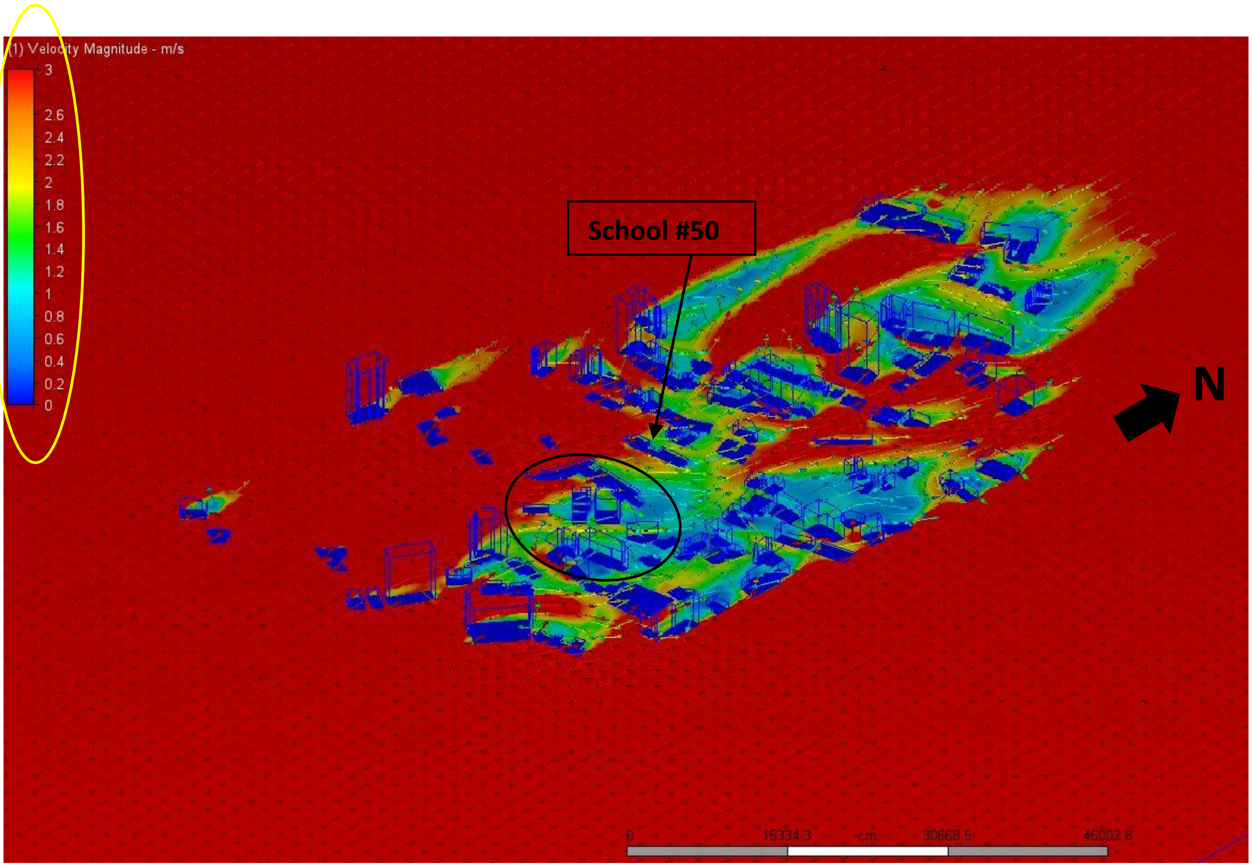



*Figure 96 - School #50: Wind Simulation (Annual) (prepared by: author)*

As we see in figure 80, the wind flows freely from the South towards the school's building, with a velocity of 3+ m/s. However, the wind is blocked on one only side by several buildings facing the school, highlighted with a black circle in the above figure, resulting in a breakage in its flow and a decrease in its velocity or speed on this side. Which means, the wind arrives at a lower speed from its normal one to the school's rooftop. Moreover, the wind arrives flows freely from other sides with a minimum velocity of 3 m/s.

### *4.4.2.5.b. Winter Wind Flow*

After clicking 'solve' in CFD, the software automatically generates a wind simulation based on all the criteria that we have given, such as the wind direction and speed or velocity. Therefore, the simulation starts appearing as a graph composed of 'iterations' which means steps, showing the wind velocity divided on the three axes x, y and z (which means in 3D mode or reality). As shown in figure 97, each criteria is represented by a line of different color on the graph. What interests us for this study is the first three lines Vx, Vy and Vz. The more these three lines are converging at

the end of the graph, which means at the end of the simulation or analysis process, the more accurate the analysis is. Consequently, better results are generated, that are closer to reality.

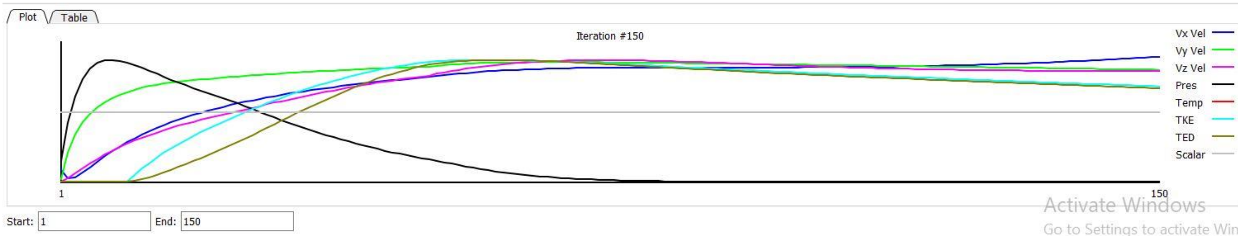



*Figure 97 - School #50: Analysis Graph (Winter) (prepared by: author)*

Figure 98 shows the wind simulation on school #50, during the winter, which means from January until March. The wind is flowing from South to North, as explained before in the previous sub-sections. The wind velocity or speed is 11 m/s, and it is minimized to 5 m/s in the below figure, in order to have a more legible simulation.

In this step we add a plane to obtain the results of the wind at the level of the school's rooftop, where the crops will be placed.

The plane is placed according to:

X=0, Y=0, and Z=1.

Meaning that this plane represents the wind flow on the horizontal level of the building's rooftop. The legend is in meter per second (m/s) and ranges from 0 to 5 m/s, showing the velocity or the speed of the wind. The vectors show the direction or the flow of the wind. As we can see in this simulation result, the velocity of the wind around the school's building on this level varies from 2.4 m/s to 5+ m/s, following the legend and its indicated colors. (Figure 98)

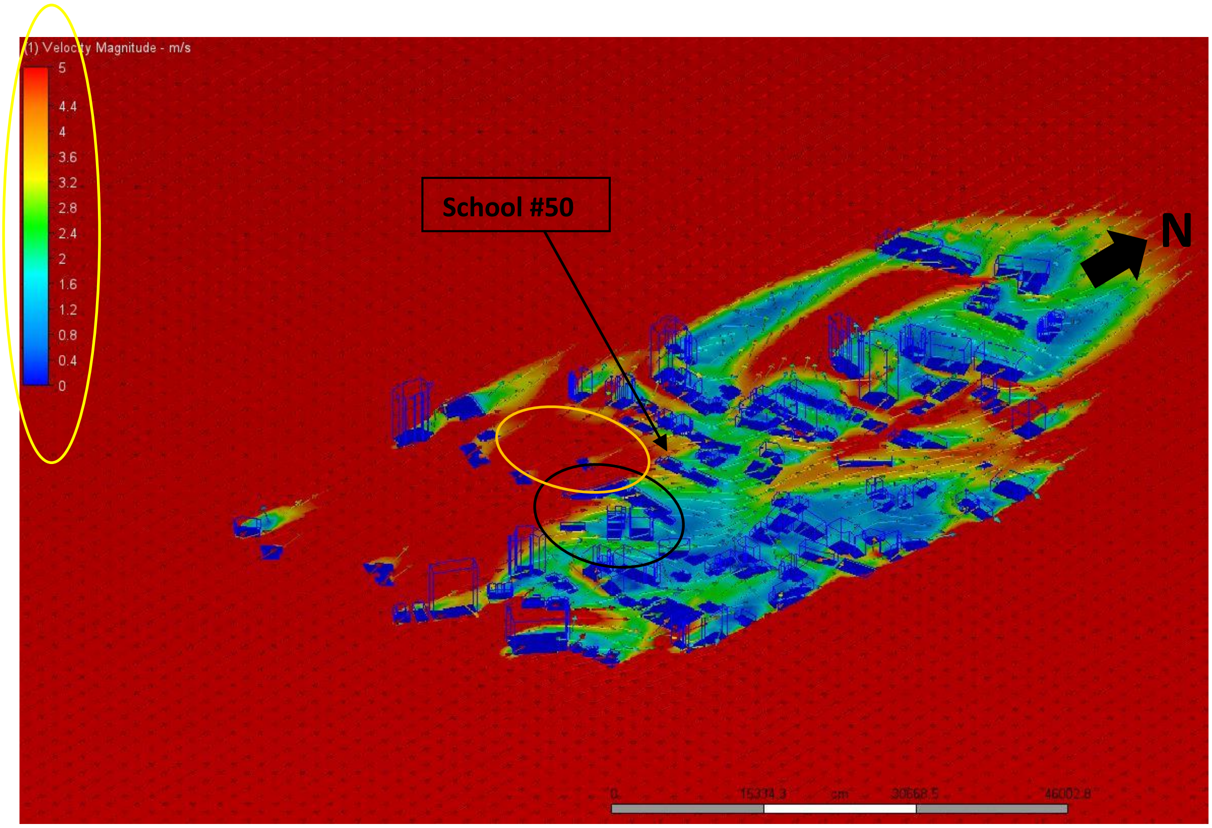



*Figure 98 - School #50: Wind Simulation (Winter) (prepared by: author)*

As we see in figure 98, the wind flows freely from the South towards the school's building, with a velocity of 5+ m/s. However, the wind is blocked by several buildings facing the school, highlighted with a black circle in the above figure, resulting in a breakage in its flow and a decrease in its velocity or speed. Which means, the wind arrives at a lower speed from its normal one to the school's rooftop from one edge. Moreover, from another edge, highlighted in an orange circle, the wind picks up its speed or velocity so it reaches its maximum, due to the fact that there are no buildings there to block the wind flow.

*4.4.2.5.c. Summer Wind Flow*

After clicking 'solve' in CFD, the software automatically generates a wind simulation based on all the criteria that we have given, such as the wind direction and speed or velocity. Therefore, the simulation starts appearing as a graph composed of 'iterations' which means steps, showing the wind velocity divided on the three axes x, y and z (which means in 3D mode or reality). As shown in figure 99, each criteria is represented by a line of different color on the graph. What interests us for this study is the first three lines Vx, Vy and Vz. The more these three lines are converging at

the end of the graph, which means at the end of the simulation or analysis process, the more accurate the analysis is. Consequently, better results are generated, that are closer to reality.

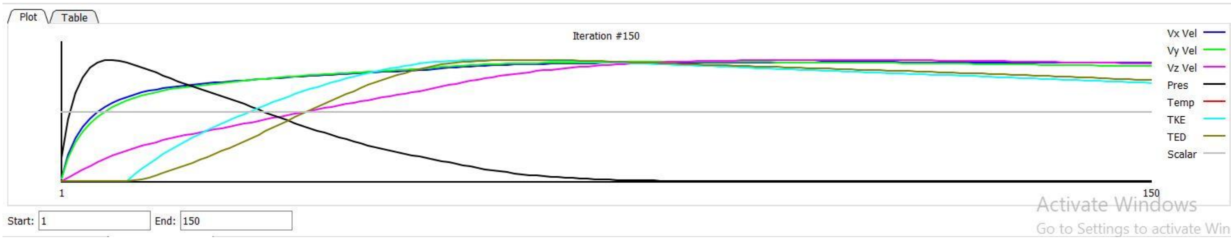



*Figure 99 - School #50: Analysis Graph (Summer) (prepared by: author)*

Figure 100 shows the wind simulation on school #50, during the summer, which means from July until September. The wind is flowing from South-West to South-East, as explained before in the previous sub-sections. The wind velocity or speed is 5.1 m/s, and it is minimized to 4 m/s in the below figure, in order to have a more legible simulation.

In this step we add a plane to obtain the results of the wind at the level of the school's rooftop, where the crops will be placed.

The plane is placed according to:

X=0, Y=0, and Z=1.

Meaning that this plane represents the wind flow on the horizontal level of the building's rooftop. The legend is in meter per second (m/s) and ranges from 0 to 4 m/s, showing the velocity or the speed of the wind. The vectors show the direction or the flow of the wind. As we can see in this simulation result, the velocity of the wind around the school's building on this level varies from 2 m/s to 4+ m/s, following the legend and its indicated colors. (Figure 100)

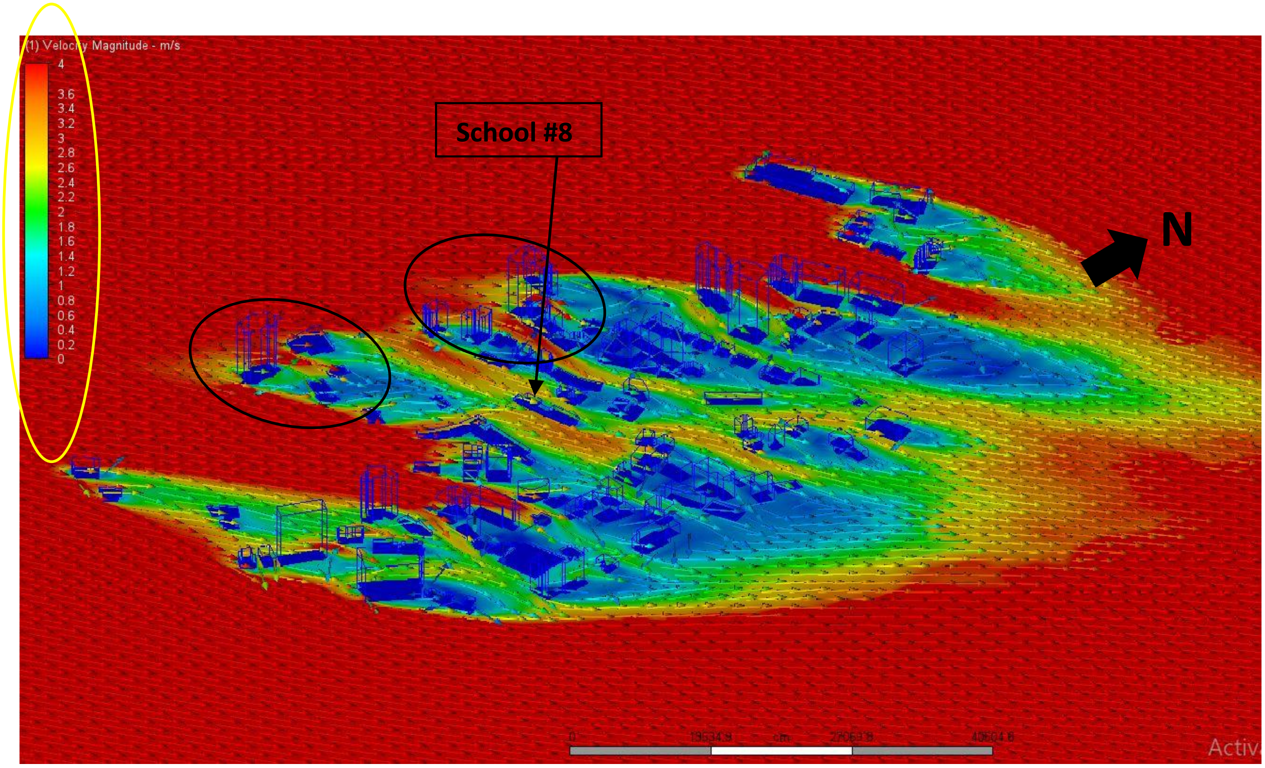



*Figure 100 - School #50: Wind Simulation (Summer) (prepared by: author)*

As we see in figure 100, the wind flows freely from the South-West towards the school's building, with a velocity of 4+ m/s. However, the wind is blocked by several buildings facing the school from two sides, highlighted with two black circles in the above figure, resulting in a breakage in its flow and a decrease in its velocity or speed. Which means, the wind arrives at a lower speed from its normal one to the school's rooftop from two edges. Moreover, as we can also see, the wind arrives at considerably high speed of 3 m/s from one side, in comparison with the other two sides.

#### *4.4.2.6. Comparison of the results for School #50*

After running three simulations for the wind flow (annual, winter and summer) and reading all the results generated from the analysis of the wind flow around School #50 rooftop, we are able to perceive the differences in the wind direction, speed and breakage around the mentioned building. These differences are due to the context, which means the neighboring buildings and their specifications, such as their height and location in comparison with the height and location of the school's building.

Around the year, the wind flows from the South mainly, that is what we call the dominant wind or prevailing wind, with a velocity or speed of 8.5 m/s. The wind reaches the school's rooftop at a maximum velocity of 8.5 m/s from one side, due to the absence of any buildings facing the school. From another side, the wind reaches the school's rooftop at a minimum velocity of 2 m/s, due to the presence of several neighboring buildings that are higher from the school's building by two levels at least. This results in a slight breakage in the wind flow from this side.

During the winter (from January until March), the wind flows from the South mainly, that is what we call the dominant wind or prevailing wind, with a velocity or speed of 11 m/s. The wind reaches the school's rooftop at a maximum velocity of 11 m/s from one side, due to the absence of any buildings facing the school. From another side, the wind reaches the school's rooftop at a minimum velocity of 2.8 m/s, due to the presence of several neighboring buildings that are higher from the school's building by two levels at least. This results in a slight breakage in the wind flow from this side.

During the summer (from July until September), the wind flows from the South-West mainly, that is what we call the dominant wind or prevailing wind, with a velocity or speed of 5.1 m/s. The wind reaches the school's rooftop at a maximum velocity of 3.2 m/s, due to the several buildings facing the school from two sides, which are higher from the school's building by at least two levels. This results in a breakage in the wind flow.

Below is table 19, showing the results compared together, for a better reading.

| | **Wind flow direction** | **Normal Velocity (m/s)** | **Minimum Velocity around the Rooftop (m/s)** | **Maximum Velocity around the Rooftop (m/s)** | **Breakage of wind flow** | **Reason of breakage** |
|---|---|---|---|---|---|---|
| **Annual** | South | 8.5 | 2 | 8.5 | Yes | Several facing buildings |
| **Winter (January until March)** | South | 11 | 2.8 | 11 | Yes | Several facing buildings |
| **Summer (July until September)** | South-West | 5.1 | 2 | 3.2 | Yes | Several facing buildings |

*Table 19 - School #50: Comparison of simulation results (annual, winter. summer) (prepared by: author)*

## 4.5. Rooftop design proposals according to the wind direction and velocity (Pilot projects: school #8 and school #50)

After conducting the analysis on the wind simulation process over the two public schools (school #8 in Ashrafieh district, and school #50 in Ras Beirut district) in municipal Beirut, the results obtained show that the dominant wind in these two locations vary in direction and velocity from summer (July until September) to winter (January until March), and also around the year.

Results, as explained in the previous section in details, show that for Ashrafieh district, which means school #8, the dominant wind is from the South-West during the winter and from the West during the summer, while it is from the South-East around the year. As for Ras Beirut district, which means school #50, the dominant wind is from the South during the winter and from the South-West during the summer, while it is from the South around the year.

Moreover, the velocity or speed of the wind also varies in these two locations from winter to summer, and on an annual basis. As explained and shown in the previous section of this Chapter, the variation in wind velocity is a consequence of a breakage in the wind flow before it reaches to the school’s rooftop. This breakage is due to taller adjacent buildings, the orientation of which blocks the wind flow.

Therefore, more research is needed to be done in this Chapter, in order first to validate the results obtained from the analysis, and second to understand if the wind direction and velocity and the change in them can effect plant growth, and if yes how? In addition, this research can give us also a guide on what types of crops are the most adequate to plant in such climate (Mediterranean weather) and what conditions we need to provide for the plants to grow faster and more abundantly.

Accordingly, sub-section 4.5.1 shows the Mediterranean climate characteristics and its effects on plant growth, in addition to the types of vegetation to grow in such climate. While 4.5.2 studies how the wind direction and velocity affect plant growth, sub-section 4.5.3 showcases the types of green rooftops, and their applications, considering the wind flow characteristics. Finally, sub-section 4.5.4 proposes design solutions for transforming a regular rooftop into a green one, following the analysis results and the research conducted, making the public schools #8 and #50 pilot projects for the rest of the public schools in municipal Beirut.

*4.5.1. Mediterranean climate characteristics and its effect on plant growth (best crops to plant)*

The Mediterranean region, with its various environments, forms a "global biodiversity hotspot" which constitutes of more than thousands of different plant species that are native, meaning they do not grow in any other region. In addition, this region is heavily impacted or shaped by various management applications that are on a long term basis (Myers et al., 2000). Moreover, the Mediterranean basin is considered one of the most important regions in the world that are the number one source for pasturage, having wide "vegetation dynamics, species distribution and landscape biodiversity" (Perevolotsky, 2005) (Henkin et al., 2010).

This biodiversity in plant species is due to the region's climate characteristics. According to Porqueddu and his co-authors in their article in 2016,

> "Mediterranean-climate zones are characterized by mild, wet winters and hot dry summers, and are associated with large intra- and inter-annual variability." *(Porqueddu et al., 2016, p. 1)*

Buddenhagen gives a specific definition for the Mediterranean climate in their study on 'Legumes and farming systems in the Mediterranean climates' in 1990, by stating that such climate maintains an average annual rainfall that ranges between two hundred and fifty millimeter (250 mm) and nine hundred millimeter (900 mm), with more than 65% of it should occur from Autumn until Spring periods in general, and during the winter in particular (Buddenhagen, 1990). In addition, Aschmann also defines this type of climate by having at least one month a year with a mean temperature below fifteen degree Celsius (15° C) (Aschmann, 1973).

Furthermore, the Mediterranean climate can be found in four regions around the world other than the Mediterranean basin itself (which is Southern Europe, North Africa and West Asia). These regions are the southern tip of South Africa, parts of Southern Australia, California and central Chile (Porqueddu et al., 2016). Mediterranean climates take place in regions with a latitude ranging between 28° and 45°. What characterizes these regions is that they act as transition zones between temperature climates and dry tropical climates (Dallman, 1998).

What interests us for this study is the Mediterranean basin itself, because the location of this study is Beirut, Lebanon (a Mediterranean city overlooking the Mediterranean Sea). Therefore, a further study on the soil of this specific region is highlighted here, extracted from the 2016 study of Porqueddu and his co-authors. The most abundant soil found in this region is broadly characterized with limestone 'of marine origin'. As a result, this region consists of a wide variety of plant species making it a unique biodiversity scene, as mentioned before, due to the presence of lime-base in its soil which is essential for plant growth. (Porqueddu et al., 2016)

Additionally,

> "The original climax vegetation in the World's Mediterranean regions has remarkably similar characteristics; this is despite their isolation and it indicates a high degree of convergent evolution. In the Mediterranean basin it is called *maquis*" (Cody and Mooney, 1978, p. 270)

Following Cody and Mooney's study in 1978, the most common vegetation type of the Mediterranean basin is characterized by 'deep-rooted evergreen shrubs' with small leaves having high specific leaf weight (Cody and Mooney, 1978) (figure 101).

*Figure 101 - 'Maquis' plants: the most common in Mediterranean Climates (Extracted from: futura-sciences.com)*

Moreover, the Mediterranean basin contains more than twenty five thousand (25 000) plant species, 50% of which are considered endemics, which means are native to this specific region (Blondel and Aronson, 1999). These plants face some challenges in this climate however, having to deal with a long period of summer drought with high solar radiation levels, low winter temperatures and more or less variable rainfall seasons (Chapman and Asseng, 2001). Consequently, vegetation has adapted to these climate challenges over the years, reducing the growth rates and mineral absorption and increasing 'concentrations of secondary metabolites' (Jochum et al., 2007) (Belgacem and Louhaichi, 2013) (Porqueddu et al., 2016). Therefore, an interactive complex relationship between the soil and the plant is developed, allowing the plants 'to maximize the use of scarce resources' due to the gained adaptive qualities (Sardans et al., 2013).

Moving on to the types of crops that grow in Mediterranean climates. Such crops are characterized by temperate fruit and nut products. A variety of fruits and nuts is native to this region such as 'Grapes, Olives, Figs, Almonds, Dates and Carobs' (Tous et al., 1996). Among these fruits, citrus and tomatoes are also considered the most significant crops in the Mediterranean regions (Patterson et al., 2005), especially in the Middle East area, where our study area lies.

*4.5.2. How does the wind direction and velocity affect plant growth?*

All types of vegetation are sensitive to climate change and conditions. Wind is an important aspect of climate conditions, and plays a significant role in altering the 'carbon fluxes', affecting the uptake and emission rates of the plants during the photosynthesis process. (Zhang et al., 2022)

Plants face many major challenges from the point when they are planted until the end when they give crops in some cases or in other cases when they die and reproduce. One of these major challenges is that they need to have 'mechanical support in order to undergo static and dynamic loading throughout their lifetime'. The most significant 'dynamic loading' on plants is the wind, having major impacts on plants' growth, their morphology, ecology and physiology (Gardiner et al., 2016). Various literature have dealt with the interaction between the wind and the plant; some have studied the wind loading on plants, while others have discussed the damaging effects of the wind on the plant (Grace, 1988) (Grace et al., 1991) (Langre, 2008) (Niklas and Spatz, 2012) (Mitchell, 2013). Therefore, these studies and many more are discussed in this sub-section in order to have a better understanding of the wind-plant interaction.

First, we need to describe the wind structure. The wind in the earth's atmosphere moves continuously, resulting in winds having different intensities which means velocities, directions and persistence. All these characteristics vary according to latitudes and locations, along with climates of course. In their study of 2016, Gardiner and their co-authors discuss that there is a difficulty in defining how the wind speed changes with a changing climate, however there is some strong evidence that shows that 'extreme wind speeds can be expected in some regions'. (Gardiner et al., 2016)

Although the wind particles move in a three dimensional manner in the atmosphere, meaning the air flows on the three planes (x, y and z), the horizontal component or planes x and y is usually taken into consideration when measuring the wind velocity or speed because the vertical component or plane z is much smaller in general (Harrison, 2014). Moreover, studies show that the most important environmental component that causes the most difficulty in the prediction of wind flow and velocity, and leads to inaccurate results in fluid simulation analysis, is the topography. Therefore, researchers state that ‘gentle hills with width to height ratios of greater than approximately ten’ can be considered as linear or horizontal, meaning the topography in this case is considered negligible (Gardiner et al., 2016). Consequently, it is validated that we discussed that the topography is not considered in the wind simulation analysis in the previous section of this Chapter.

According to Hamilton and Derzaph in their 2013 study on the ‘Effects of wind on virtual plants in animation’, plants are directly affected by the wind through ‘physical motion’ which results in impacts on growth over time. Meaning that

> “Wind’s contact with a plant immediately causes physical motion by bending, swaying, or twisting the stems or leaves.” (Hamilton and Derzaph, 2013, p. 1)

Hamilton states that over a period of time the wind affects the plant growth through its strength and duration. Consequently, plants react through three main manners; an increase in the girth of the stem, a decrease in the length of the stem, and a change in the direction of the growth occurs (Hamilton and Derzaph, 2013). Moreover, there are two changes also that happen in the leaves of the plant; an increase in their thickness and a re-shaping of their form resulting in a more rounded and stunted shape (Oertli et al., 1978) (Anten et al., 2010).

As for the bending of stems and roots, plants have developed an ability in load bearing. Aside from the wind loading, there is the loading that is due to the plant’s own weight, especially in the cases where there is an asymmetry in the canopy or leaves, which is all related to the plant’s growth. As a result, plants ‘have adapted to deal with this type of loading where the internal stem structure and the morphology of the plant is designed and developed to resist this loading and to avoid buckling or collapse’; in rare cases where we see the plant collapsed, it is due to the failure in developing this type of ability in load bearing. Additionally, plants also have to uphold and maintain a certain orientation or stature in order to ensure maximum light capture for photosynthesis. (Fournier et al., 2013) (Gardiner et al., 2016)

Circling back to the loading that the wind exerts on the plant, it is important to note that the plant, as mentioned before, develops a capacity to resist loadings and breakage resulting from the loadings, due to its ability to create and grow 'elastic restoring forces in the stem and the root system' (Coutts, 1986). Plants, as structures, possess safety margins in which the plant is controlled and safe from collapse or breaking; however, exceeding these margins with strong wind for example leads to a collapse in the plant, which in turn may lead to a damage or dryness that stops the reproduction process for some plants, meaning that the plant dies (Bruechert et al., 2000) (Gardiner et al., 2016).

Moreover, most studies discuss the damage that the wind leaves on herbaceous plants, especially food crops due to their economical and commercial importance. Plants, such as cereals (wheat most importantly, barley, maize, oats and rice), are at the front of these studies' focus (Gardiner et al., 2016). This damage has negative results on the economic aspect of food crops, as it decreases the yielding, meaning the quantity of the food crops becomes less, which is turn increases the prices; this is following the basic economic law of supply and demand, a decrease in supply and an increase in demand lead to high prices of products (Baylis and Wright, 2008) (Kramer, 2021).

As mentioned previously, the wind leaves a damage on plants. Therefore, various studies discussed ways and tools to help prevent or minimize the effect of the wind on plants (Baker et al., 2014) (Gardiner et al., 2016) (Zhang et al., 2021). Some studies suggest different tools to reduce wind velocity such as windbreaks. Windbreaks are basically shields, made of transparent plastic sheets that do not prevent light integration, along with steel tubes that act as structure for the plastic sheets; these shields are built around the plant in order to protect it from increased wind velocity that may lead to damage in plant growth or even breakage of the plant (Werger et al., 2010) (Zhang et al., 2021) (figure 102).

*Figure 102 - Wind Shields to help reduce wind velocity around the plant (Extracted from: Zhang, 2021)*

Other studies propose tools to enhance or increase the wind velocity around the plant, when the velocity is really low. This is important, due to the fact that the wind velocity contributes in some cases in enhancing plant growth when it is between safety margins, as discussed previously. These proposed tools are such as wind baffles, which are made of iron sheets in order to withstand the wind flow, and are placed around the plant in a way to direct and converge the wind, therefore increasing the wind velocity as it reaches the plant. These sheets are also placed at a certain distance from the plant pot in order to avoid casting shade on the plant (Liu et al., 2006) (Zhang et al., 2021) (figure 103).

*Figure 103 - Wind Baffles to help increase wind velocity around the plant (Extracted from: Zhang, 2021)*

In addition, wind flow and velocity affect the photosynthesis process. Being a natural biochemical process that is essential in the plant's life, photosynthesis relies on the plant's exposure to light and 'the gaseous exchange through the stomata', which means the small pores on the leaves' surface (Sinoquet et al., 2001) (Smith and Ennos, 2003). According to Langre in their study of 2008 on 'Effects of wind on plants', wind's impact on the photosynthesis process is through several major aspects. First, the wind affects the gaseous exchange, mentioned before, by convection; meaning the particles of the wind that are the closest to the small pores of the plant's leaf, or the stomata, move continuously, creating a dynamic process where a current of constantly moving winds is born, which accelerates and maximizes the exchange of Oxygen (O2) and Carbon Dioxide (CO2) (the process of photosynthesis). The second effect of wind on the photosynthesis process is through light shedding. As mentioned at the start of this sub-section, the direct contact of the wind with the plant is through physical motion such as by swaying. As the wind moves the top leaves of the plants, the lower leaves are exposed to more light and also wind, resulting in a more efficient photosynthesis process for the whole plant. (Tong and hipps, 1996) (Roden, 2003) (Langre, 2008)

Furthermore, some studies show experiments done on the impacts of wind on the plant growth rate, and observations were presented. The plant is placed in a wind tunnel for simulation. The results demonstrate that the growth rate increases at low wind velocities, and decreases when wind speed in further increased. Moreover, a standard wind velocity of 0.3 m/s is proven to be the most optimal wind velocity or speed where the growth rate of the plant is the most ideal in terms of time and nutrients. (Wadsworth, 1959) (Bergman et al., 2020)

*4.5.3. Types of green rooftops to be implemented accordingly*

Following the Literature Review in Chapter 2, most studies that discuss the subject of green rooftops, or vegetated rooftop, state that there are three types of green roofs (Nowak, 2004) (Hui, 2011) (Rogers, 2013) (Reese, 2014) (Walters et al., 2018). These three types are called extensive roofs, intensive roofs, and hydroponic gardens, and they are discussed in details in the following sub-sections. These roofs differ from each other by the way of application, their design and the types of crops they produce (over the course of a year or seasonal), and each type of roof is beneficial in its own way.

*4.5.3.a. Extensive green roof*

Like the name implies, this type of green roof is usually installed on the whole area of the roof or to the 'extents' of the roof, which explains the naming. These roofs have shallow depth of growing medium, soil being the primary one; shallow depth meaning less than fifteen centimeters (15 cm)

(Walters et al., 2018). Nicole Reese states in her dissertation of 2014 that this type of roofs is not typically installed for the purpose of food crops production, nor for recreational purposes, but rather for the goal of 'improving building performance and extending roof life'. Plants used in this type of roof are usually low root plants such as grass, mosses and succulents (Bay Localize, n.d.). In the case of utilizing the extensive green roof for growing food, it is best advisable to plant herbs and low root vegetables such as leafy greens because they are the most suitable vegetables for this type of green roof having shallow depth of soil (Foss et al., 2011) (Reese, 2014).

Moreover, extensive green roofs usually need less maintenance, due to their shallow depth of growing medium (Walters et al., 2018), and also need less irrigation, relying mainly on rain water for getting the water needs for the plants (Rogers, 2013).

#### *4.5.3.b. Intensive green roof*

In comparison with the extensive green roof, the intensive green roof type is characterized with deeper growing medium, such as soil, having a depth more than fifteen centimeters (15 cm) (Walters et al., 2018). This depth allows for the installation of a more variety of plants and vegetation, such as small trees, shrubs, and a wide selection of food growing plants. In addition, various landscape features, such as paths, bench seating, water features and even irrigation systems, are allowed to be installed in an intensive green rooftop (Velazquez, 2005) (Kwok and Grondzik, 2011) (Walters et al., 2018).

Moreover, Judy Rogers states in her conference paper of 'Sustainable development and planning VI' in 2013 that:

> "Intensive green roofs provide accessible open space […]. As a result, intensive green roofs require high level of maintenance." (Rogers, 2013, p. 325)

Therefore, this type of green rooftop is suitable for flat roofs having a large area. Additionally, this type of roof is feasible for buildings that can withstand additional load of their rooftops; thus, it is advisable to study the structure of the building in defined details in order to conclude if the roof can be transformed into an intensive green one. (Tourbier, 2011)

Consequently, an intensive green roof is more costly than an extensive green one, however it is more sustainable in terms of energy efficiency due to the fact that it covers the whole roof area, in addition to having ‘the capacity for greater storm water retention’. (Rogers, 2013)

*4.5.3.c. Hydroponic roof garden*

Another type of green roof application is a hydroponic roof garden, which is a space for growing plants and vegetables using a growing medium other than soil. Crops are grown in water ‘with controlled nutrient minerals in the solution’. Nicole Reese, in her study of 2014, discusses that this type of green roof is the lightest of all agriculture rooftop due to the absence of soil or any other somewhat heavy growing medium; therefore it is the most suitable type of green roof to be applied to a building with structural limitations (Reese, 2014).

Moreover, hydroponic systems are able to produce approximately the same amount of food from crops in the fifth (1 / 5) of the space that the other types of green roofs need. Plus, because the vegetation and plants use water as a growing medium, this form of roof gardening is able to reduce the need of water for irrigation by approximately ninety percent (90 %) in comparison to other types of green roof and even traditional gardening (Foss et al., 2011).

However, this type of green roof system have various disadvantages to it, when compared to the other types. It requires more costly equipment and needs technical expertise, in addition to significant energy inputs and constant maintenance (Foss et al., 2011). Growing food from crops is the only benefit from this form of rooftop agriculture, being that it does not manage storm water or rain water, and it also does not any impact whatsoever on urban heat island effect as the other form of rooftop agriculture have (Bay Localize, 2007) (Reese, 2014).

*4.5.3.d. Structure of the green roof*

One thing common in all the studies that discuss the types of green roof system, is that the structure or composition of the green roof is somewhat the same for all types.

As Michelle Nowak states in her thesis about ‘Urban agriculture on the rooftop’ in 2004,

> “A green roof is built using ‘a special root and water proof membrane for the base layer, than the root barrier, a retention or drainage layer, plus the soil layer, and finally the plants.” (Nowak, 2004, p. 23)

At the start of the green roof industry, it has been made clear that accessibility to roof infrastructure maintenance is of significant importance, and during the initial phases of this industry, this accessibility was really difficult and too costly. As a response, the industry created the concept of modulation, and produced modular green roof system, where each part of the green roof system can be moved individually, making it easier for accessibility and giving it a dynamic ability to change and adapt to new changes. (Wilson and Pelletier, 2003) (Nowak, 2004)

Moreover, a main factor that determines the feasibility and viability of a green rooftop system installation is the roof structural loading and the building structural capacity (CUGE, 2010).

Furthermore, many studies have suggested to always use endemics, meaning native plants specific to the area of the study, due to the fact that they are already adapted to the local climates. (Butler et al., 2012) (Tran et al., 2019)

*4.5.3.e. Interview with a Civil Engineer*

Following the research in the previous sub-sections of this chapter, an interview was conducted with Mr. Jean Pierre Succar, who is a civil engineer having more than ten years of experience of working on site, in order to validate the research and to adequately propose which type of rooftop to be implemented on each of the schools #8 and #50 according to their existing structure.

Mr. Succar studied this research briefly, and took a closer look on the gathered data of the two public schools #8 and #50, specifically on the structure of each of the buildings. The data gathered is presented in the following sub section as a ‘brief on the public school’. Mr. Succar concluded that, because of the difference in the year of construction of each of the school #8 and #50, we can somehow categorize the schools into two groups, the ones being built before the year 2000 and the ones being built after. Due to his years of experience, he suggests that the buildings constructed before the year 2000, specifically in the 1960s until 1980s, have thicker structure because the materials such as concrete were back then of better quality. However, he advises not to add heavy additional loads on these buildings, due to the huge gap of time passing since the construction, resulting in a doubtful additional load bearing of the structure. As for the buildings that are constructed after the year 2000, he adds that due to the developed technology of the construction materials, such as the concrete, the structure now allows to go higher, having more levels than before. Therefore, he commends the possibility of having heavy additional loads on these buildings.

In addition, Mr. Succar suggested some adequate materials to use for the design proposals of the green rooftop suggested in this study. The suggested materials are as follows: wood panels to form the pot where the vegetation is planted, a raised podium made of TOT steel or corrugated steel or aluminum, being a light material, this raised podium allows having space for a drainage system underneath that is connected to the building's system, in order to get rid of excessive water from irrigation, without the need to cut through the roof slab and risk having a failure in the existing structure of the building.

#### *4.5.4. Design proposals for School #8 and School #50: turning an existing rooftop into a green one – Pilot project*

In this sub-section, two green roof design are proposed, each one separately for school #8 and school #50. In order to come up with suitable design proposals and suggestions, the school building itself is assessed and studied furthermore. Note that, as mentioned in the limitations section in Chapter 3, only a brief site visit was allowed to each school due to the situation of COVID 19 and the country; therefore, all data is created and design proposals are based on theory.

Accordingly, the sub-section presents a brief on the school, meaning the building, the context, the area of the roof and its current uses or functions, the board of the school along with the students, instructors and educational program. The following sub-section showcases the design proposal for the suggested green rooftop, and explains furthermore how to turn the existing school's roof into a green one and who to involve in the process of transformation and the maintenance and operation later on.

##### *4.5.4.a. Design proposal for the green roof for School #8*

As mentioned in the previous sub section, *Lor Moughayzel High School for Girls* was constructed in 1969. Following the suggestions of Mr. Succar, as explained in 4.5.3.e., the building in question belongs to the first category of buildings constructed before the year 2000. Therefore, it is advisable to have a lighter type of structure in the design proposal in transforming the existing rooftop into a green one.

Moreover, according to the literature review done in sub section 4.5.3., the 'extensive green roof system' is the most adequate type of green roof system in the case of this building in question in this sub section.

In addition, a modular system is considered to be the best option to propose a design, due to the fact that this research is conducted on two public schools in municipal Beirut that are similar to all the others. Meaning that, the proposed design for *Lor Moughayzel High School for Girls* green rooftop can be applied the same for the similar public schools in municipal Beirut, by only moving around the modules in order to fit better the area of the roof. Plus, the modular system gives a dynamic, flexible and ever-changing design for each space it occupies, resulting in a shorter period of time needed for the field work and deep analysis of the roof of the new school.

Figure 104 shows the module system for extensive green roof in plan, while figure 105 shows the same system in section in order to understand the relationship to the existing roof.

As discussed previously, the extensinve green roof system holds a soil depth less than fiften centimeters (15 cm), meaning that we can only plant low root vegetation such as herbs like parsley, mint, rocca, etc.

As shown in the below figures, wood panels of 2 mm form together the pot where the vegetation is planted, the pot's dimensions are 1 m x 1 m x 30 cm. A podium is raised in order to allow space for the drainage system for the excessive water from irrigation and also rain water since this is an extensive green roof system. The raised podium is made out of TOT steel (corrugated steel), due to its light weight, low cost and minimum need for maintenance; while the structure of the raised podium is steel columns 10 cm x 10 cm x 15 cm, placed in a manner to withhold the path and the pots.

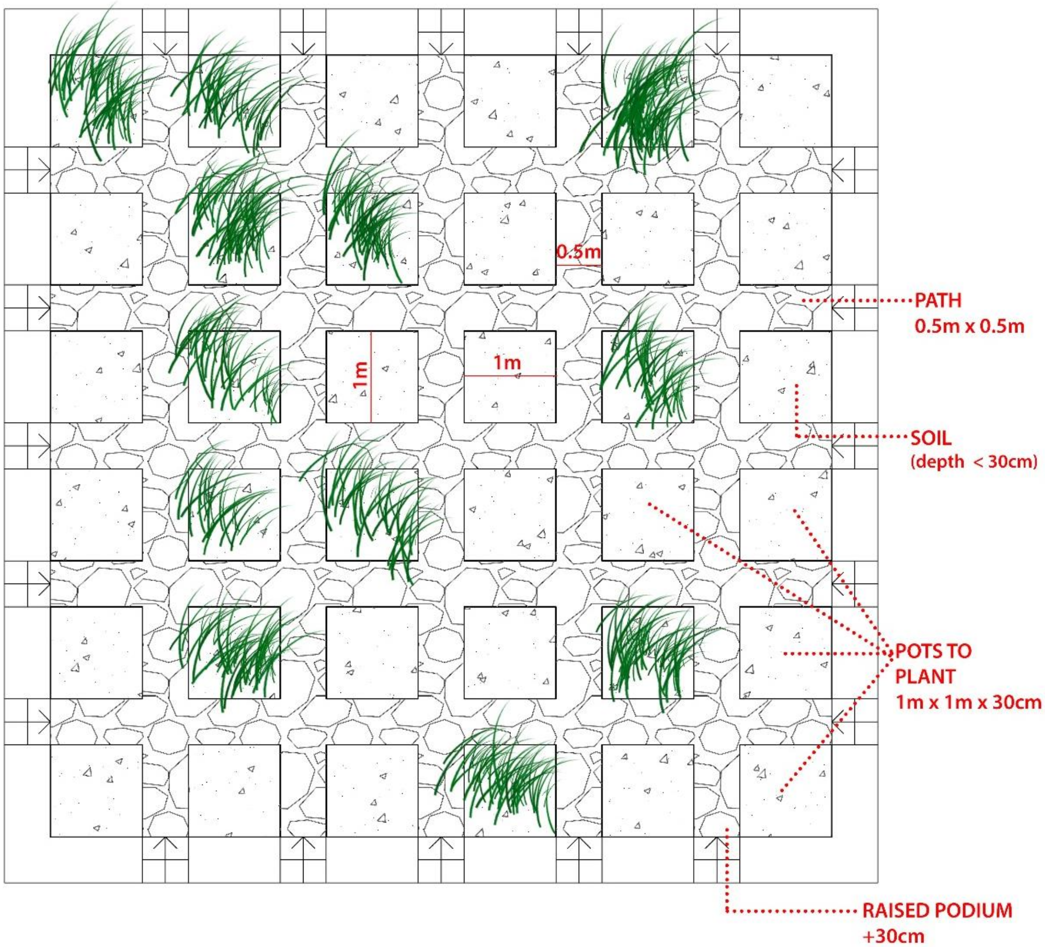



*Figure 104 - Module System for extensive green roof - plan (Prepared by: author)*

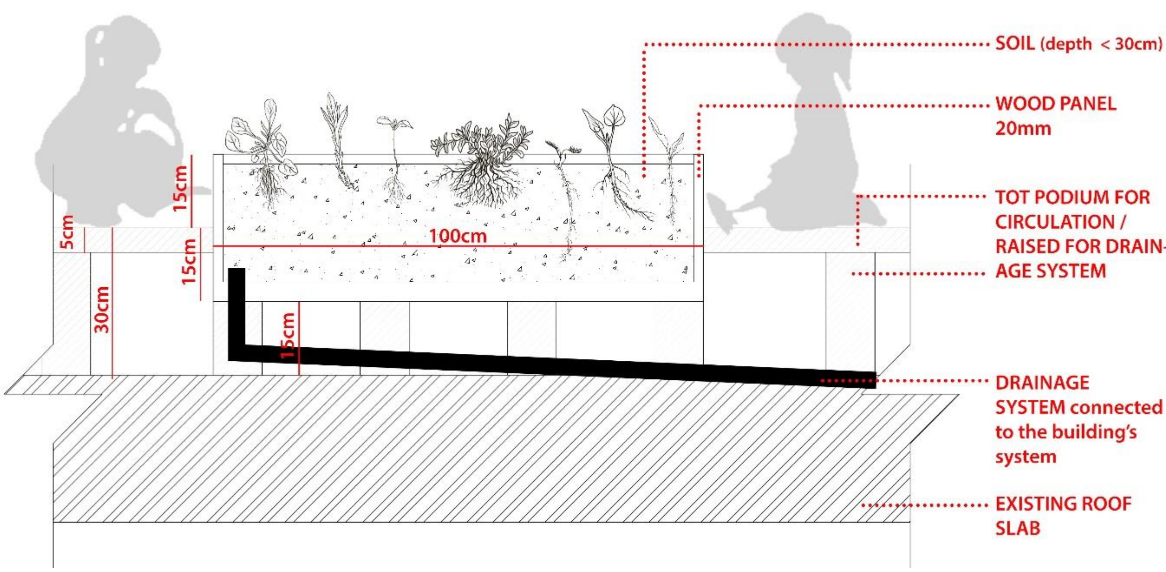



*Figure 105 - Module System for extensive green roof - section (Prepared by: author)*

Figure 106 shows the 3D view of the proposed preliminary design of the module system for extensive green roof. The module here is formed of thirty six pots to plant with a path of 0.5 m x 0.5m all around. Being a module system, having the flexibility and dynamisim to change, the module itself can be adapted into different dimensions and also shapes, following the area and shape of the roof of the school.

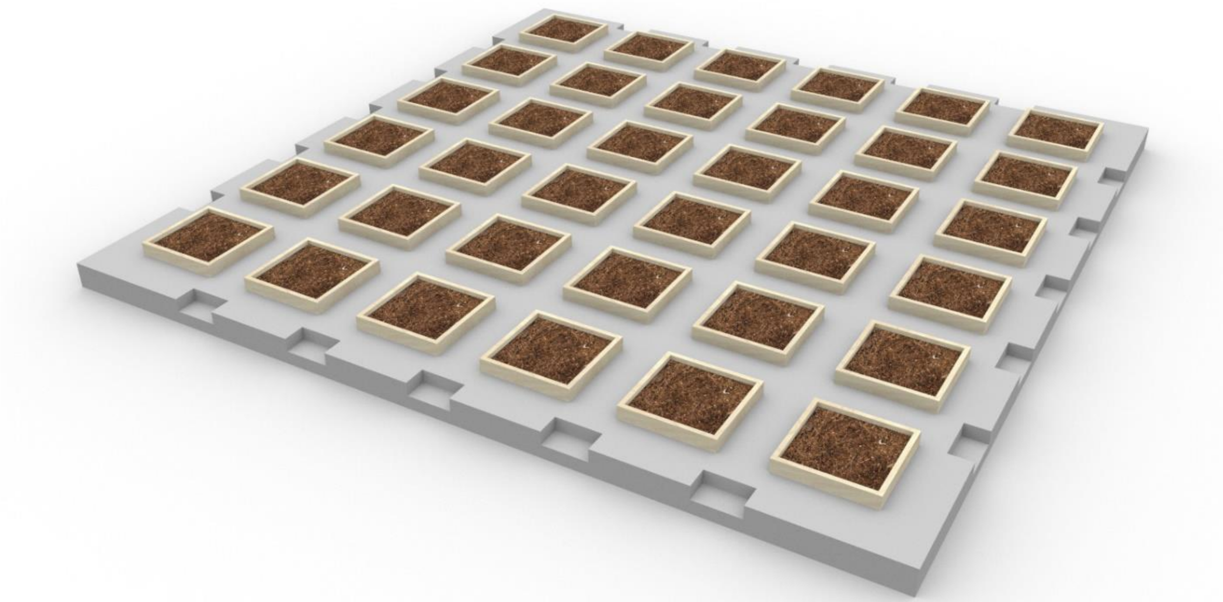


*Figure 106 - Module System for extensive green roof - 3D view (Prepared by: author)*

Figure 107 shows the suggested design of extensive green roof system for the rooftop of *Lor Moughayzel High School for Girls*.

Five modules are implemented on this rooftop according to its area. Following the existing access to the rooftop, a covered circulation path, of 1 m width, is proposed around the roof, around its edges, leaving the inside of the roof area for the modules to be placed. As mentioned previously, this preliminary proposed design for this module includes thirty six pots to plant, however this can be modified according to the needs in reality.

Following the literature review done in 4.5.3, the most optimal wind velocity for plant growth is 0.3 m/s. According to the analysis done in sub section 4.4. on the wind flow and velocity around the rooftop of the school's building, the wind flows annually from South-East with a minimum velocity of 1 m/s and a maximum velocity of 1.8 m/s. Therefore, wind baffles are implemented on the outside edge of the circulation path, and they are movable in order to allow more wind flow when needed. The wind flows during the winter from South-West with a minimum velocity of 4 m/s and a maximum velocity of 8.5 m/s. Therefore, wind breaks or shields are implemented on the outside edge of the circulation path, and they are not movable in order to control the wind velocity. The wind flows during the summer from West with a minimum velocity of 0 m/s and a maximum velocity of 1 m/s. Therefore, wind baffles are implemented on the outside edge of the circulation path, and they are movable in order to allow more wind flow when needed.

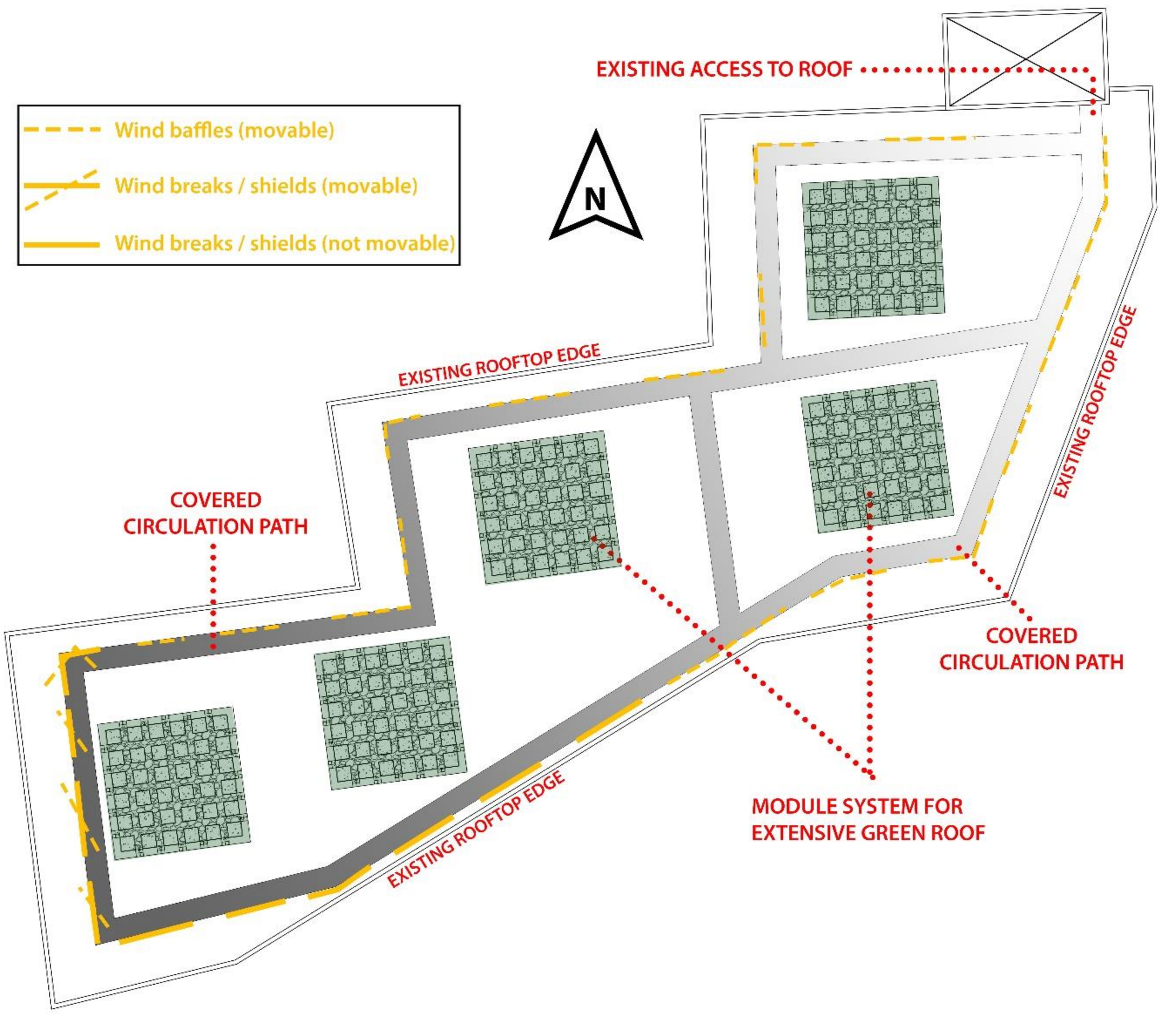



*Figure 107 - Extensive green roof system for Lor Moughayzel High School for Girls - plan (Prepared by: author)*

The wind baffles and wind breaks or shields are made of transparent plastic sheets, in order to not prevent light penetration to the plant, along with steel tubes for structure. In addition, they are placed at a distance from the plants in order not to have any influence on their growth. This design proposal is based on the literature review conducted, and it shows in the below figures 108 and 109.

*Figure 108 - Wind Shields to help reduce wind velocity around the plant (Extracted from: Zhang, 2021)*

*Figure 109 - Wind Baffles to help increase wind velocity around the plant (Extracted from: Zhang, 2021)*

### *4.5.4.b. Design proposal for the green roof for School #50*

As mentioned in the previous sub section, *Jaber Ahmad Al Sabah Public School* was constructed in 2009. Following the suggestions of Mr. Succar, as explained in 4.5.3.e., the building in question belongs to the second category of buildings constructed after the year 2000. Therefore, it is allowed to have a heavier type of structure in the design proposal in transforming the existing rooftop into a green one.

Moreover, according to the literature review done in sub section 4.5.3., the ‘intensive green roof system’ is the most adequate type of green roof system in the case of this building in question in this sub section.

In addition, a modular system is considered to be the best option to propose a design, due to the fact that this research is conducted on two public schools in municipal Beirut that are similar to all the others. Meaning that, the proposed design for *Jaber Ahmad Al Sabah Public School* green rooftop can be applied the same for the similar public schools in municipal Beirut, by only moving around the modules in order to fit better the area of the roof. Plus, the modular system gives a dynamic, flexible and ever-changing design for each space it occupies, resulting in a shorter period of time needed for the field work and deep analysis of the roof of the new school.

Figure 110 shows the module system for intensive green roof in plan, while figure 111 shows the same system in section in order to understand the relationship to the existing roof.

As discussed previously, the intensinve green roof system holds a soil depth more than fiften centimeters (15 cm), meaning that we can plant deep root vegetation such as tomatoes, eggplants, potatoes, carrots, etc., and also some small trees such as citrus.

As shown in the below figures, wood panels of 2 mm form together the pot where the vegetation is planted, the pot’s dimensions are 1 m x 1 m x 65 cm. A podium is raised in order to allow space for the drainage system for the excessive water from irrigation since this is an intensive green roof system. The raised podium is made out of TOT steel (corrugated steel), due to its light weight, low cost and minimum need for maintenance; while the structure of the raised podium is steel columns 10 cm x 10 cm x 15 cm, placed in a manner to withhold the path and the pots.

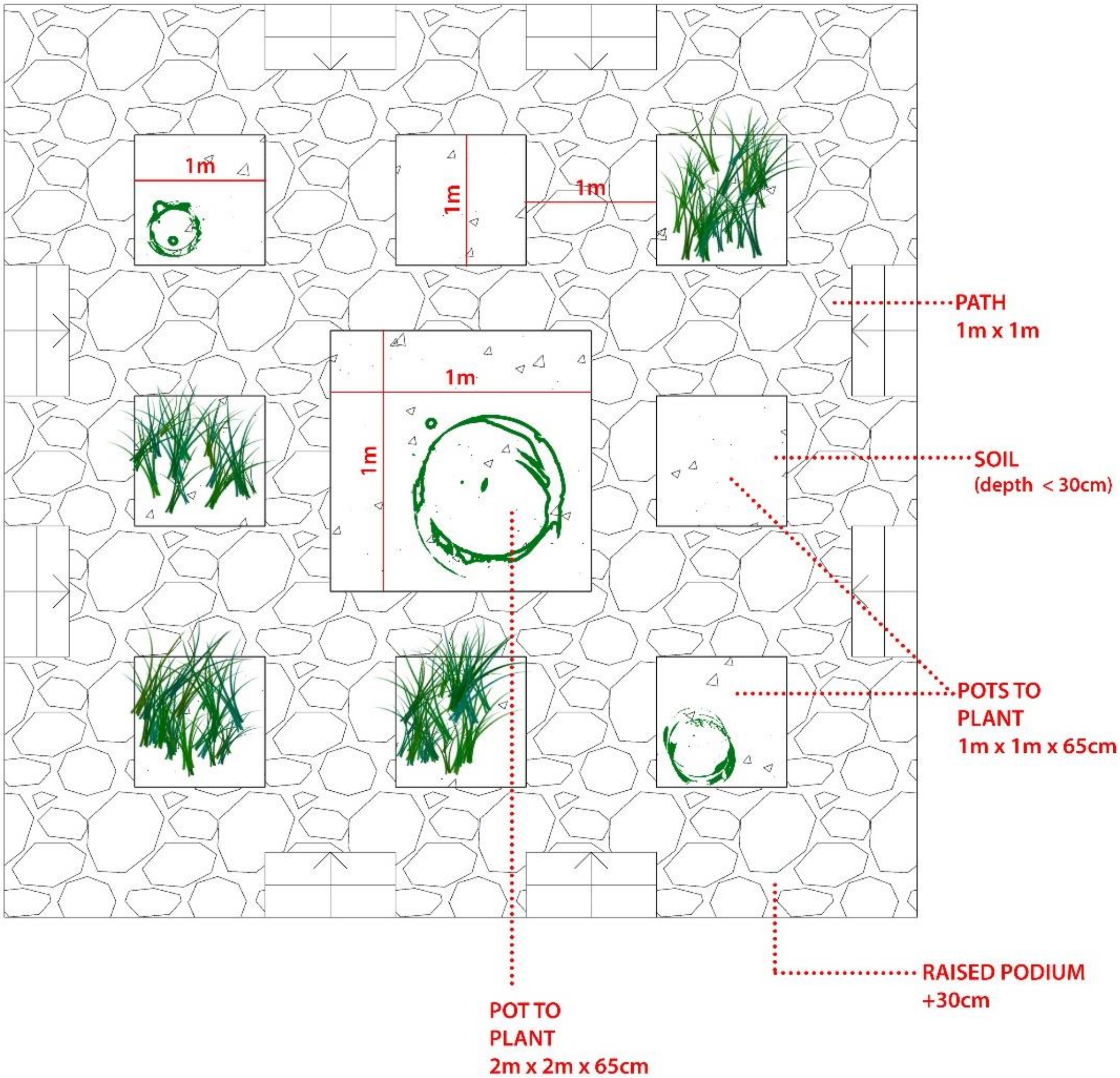



*Figure 110 - Module System for intensive green roof - plan (Prepared by: author)*

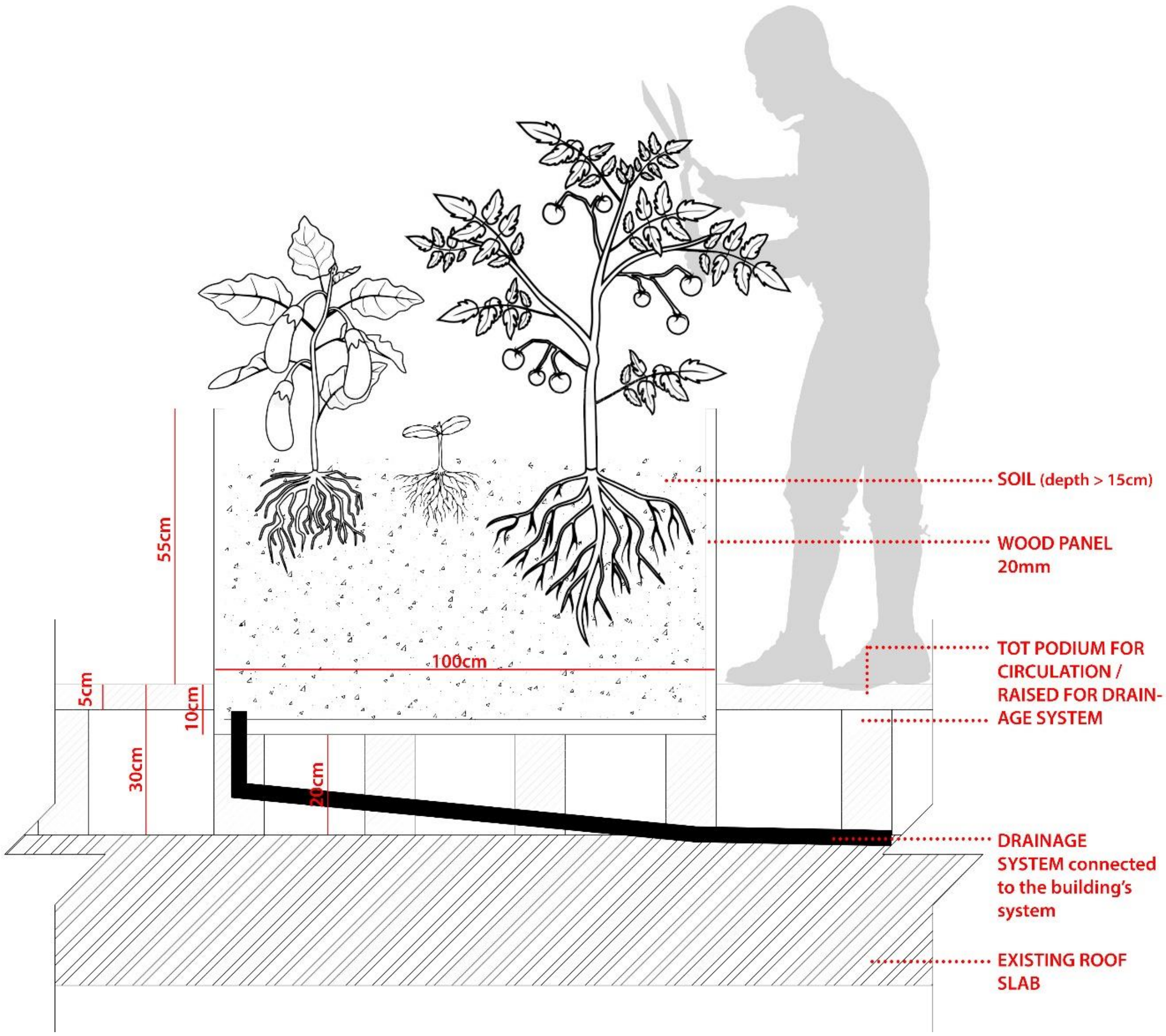



*Figure 111 - Module System for intensive green roof - section (Prepared by: author)*

Figure 112 shows the 3D view of the proposed preliminary design of the module system for intensive green roof. The moule here is formed of nine  pots to plant with a path of 1 m x 1 m all around. Being a module system, having the flexibility and dynamisim to change, the module itself can be adapted into different dimensions and also shapes, following the area and shape of the roof of the school.

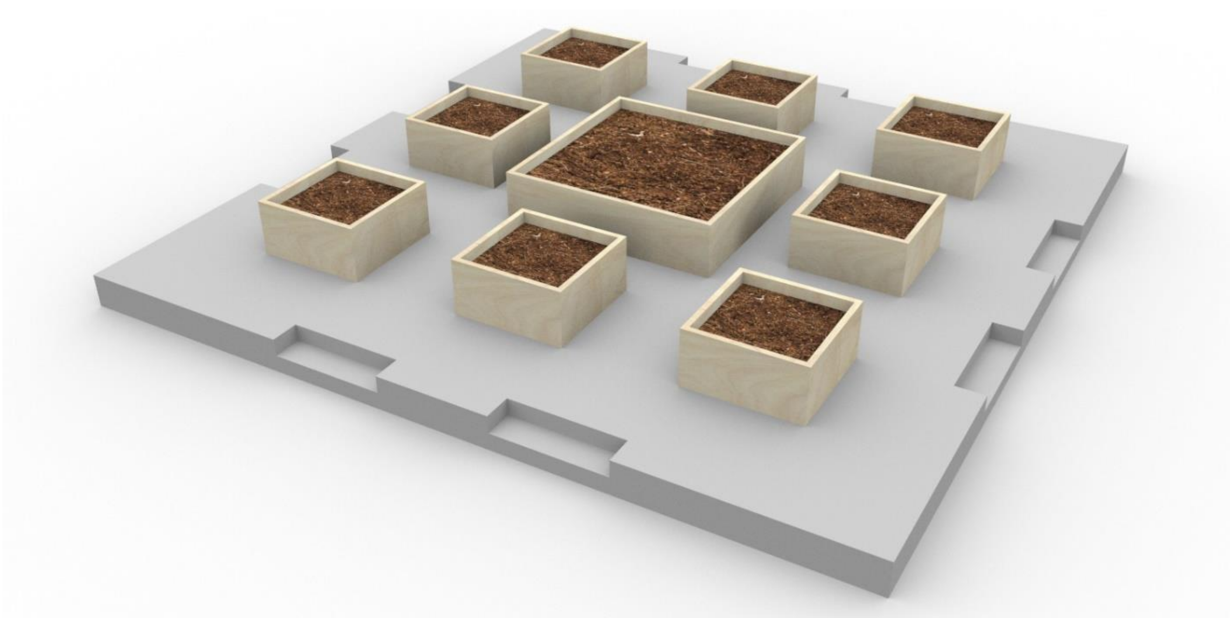


*Figure 112 - Module System for intensive green roof - 3D view (Prepared by: author)*

Figure 113 shows the suggested design of intensive green roof system for the rooftop of *Jaber Ahmad Al Sabah Public School*.

Five modules are implemented on this rooftop according to its area. Following the existing access to the rooftop, a covered circulation path, of 1 m width, is proposed around the roof, around its edges, leaving the inside of the roof area for the modules to be placed. As mentioned previously, this preliminary proposed design for this module includes thirty six pots to plant, however this can be modified according to the needs in reality.

Following the literature review done in 4.4.3, the most optimal wind velocity for plant growth is 0.3 m/s. According to the analysis done in sub section 4.3. on the wind flow and velocity around the rooftop of the school's building, the wind flows annually from South with a minimum velocity of 2 m/s and a maximum velocity of 8.5 m/s. Therefore, wind breaks or shields are implemented on the outside edge of the circulation path, and they are not movable in order to control the wind velocity. The wind flows during the winter from South with a minimum velocity of 2.8 m/s and a maximum velocity of 11 m/s. Therefore, wind breaks or shields are implemented on the outside edge of the circulation path, and they are not movable in order to control the wind velocity. The wind flows during the summer from South-West with a minimum velocity of 2 m/s and a maximum velocity of 3.2 m/s. Therefore, wind baffles are implemented on the outside edge of the circulation path, and they are movable in order to allow more wind flow when needed.

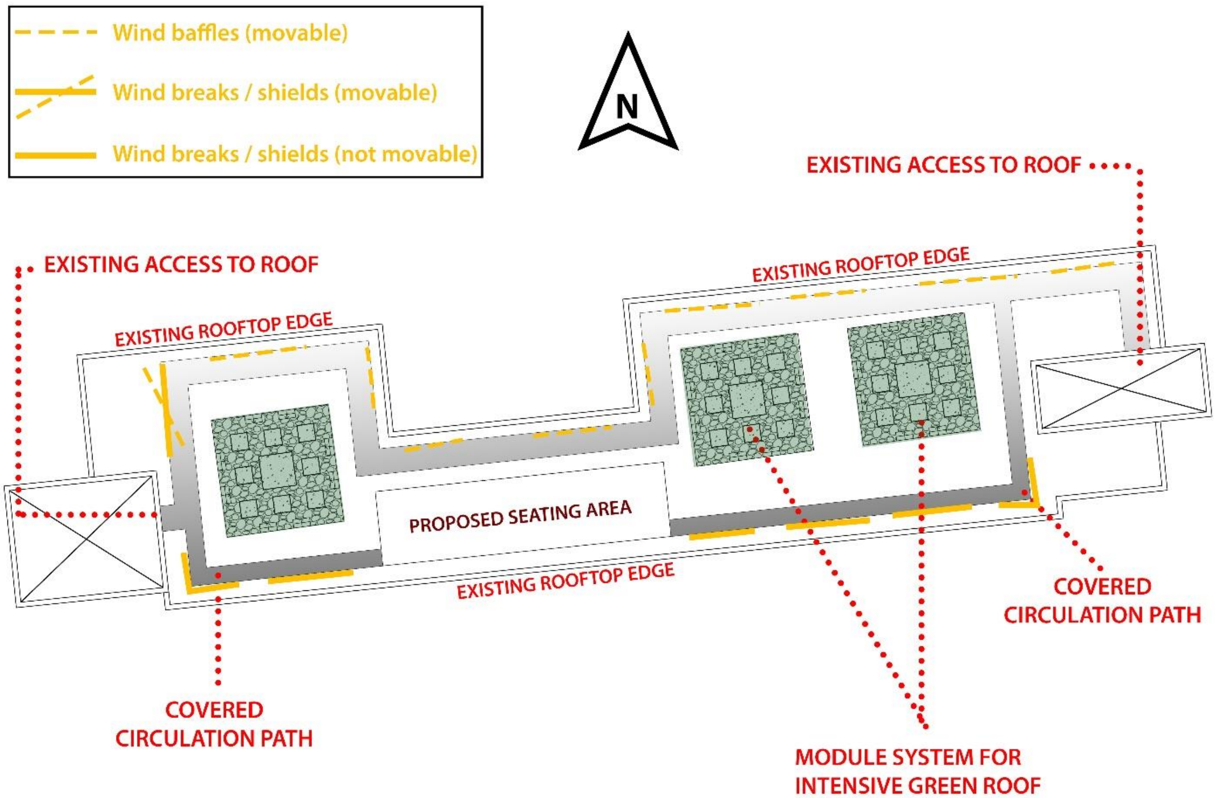



*Figure 113 - Intensive green roof system for Jaber Ahmad Al Sabah Public School - plan (Prepared by: author)*

The wind baffles and wind breaks or shields are made of transparent plastic sheets, in order to not prevent light penetration to the plant, along with steel tubes for structure. In addition, they are placed at a distance from the plants in order not to have any influence on their growth. This design proposal is based on the literature review conducted, and it shows in the below figures 114 and 115.

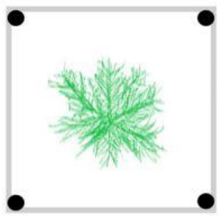


*Figure 114 - Wind Shields to help reduce wind velocity around the plant (Extracted from: Zhang, 2021)*

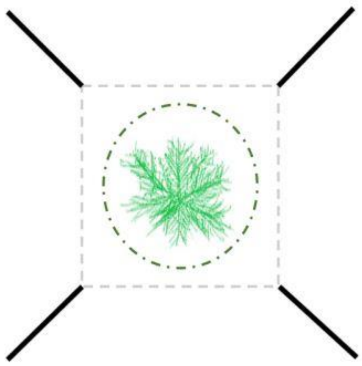


*Figure 115 - Wind Baffles to help increase wind velocity around the plant (Extracted from: Zhang, 2021)*

## 4.6. Synthesis

As a conclusion for this chapter, two public schools were chosen to be the case studies for the analysis process. School #8 in Ashrafieh district and School #50 in Ras Beirut District are chosen after a process of filtering. Later, an analysis on the wind flow and velocity around each of the school's building is conducted using the softwares Revit, CFD, and gbs[6]. Each building underwent an analysis of wind velocity and flow annually, during the summer and during the winter, showing the pre dominant wind in each case, and the minimum and maximum wind velocities around the

[6] gbs: Green Building Studio

rooftop. Next a briefly detailed literature review is done, supporting the literature review in Chapter 2, showcasing more existing research about the types of green rooftops, their structure, the types of plants to be used in the Mediterranean climate, and the influence of the wind flow and velocity on the plant growth. In addition, an interview is conducted with a civil engineer, who recommended the use of certain materials according to the structure of the building and the additional load to be added by the design proposals.

Finally, a preliminary design is proposed for each school, according to the brief data on the structure of the building (concluded only from the age of the building), and also the roof geometry. The design proposals include a modulation system for each type of green roof system suggested, a covered circulation path around the roof and having the wind baffles or wind breaks according to the results of the wind analysis on the building.

# **Chapter 5-** Conclusion

In conclusion, this thesis has examined the feasibility and potential benefits of implementing sustainable and "green" rooftops on existing school buildings in Beirut, Lebanon. The research aimed to answer the fundamental question of how existing school buildings' rooftops can be reformed to become environmentally friendly spaces and the resulting impact on the schools themselves, as well as the broader cityscape. By employing a quantitative methodology that incorporated Revit and Computational Fluid Dynamics (CFD) analysis, this study focused on wind analysis as a crucial factor in designing green rooftops and selecting suitable vegetation.

The findings of this research shed light on two primary types of green rooftops that can be economically applied to existing buildings in Beirut. It was revealed that the choice of greenery and rooftop design depends on the specific characteristics of each building and its surrounding context. Additionally, the direction and velocity of the wind emerged as critical considerations, directly influencing the selection of vegetation that can thrive in such environments.

Through a comprehensive review of existing literature, this study successfully synthesized data and insights from previous studies conducted in various countries. By applying this knowledge to the Lebanese context, where the need for urban green spaces is particularly pronounced, this research contributes to the existing body of knowledge on green rooftops. It underscores the importance of introducing sustainable practices and green infrastructure in densely populated urban areas like Beirut. Moreover, this research demonstrates the potential for adapting and implementing successful strategies employed in other countries to address the unique challenges faced by Lebanon's urban environments.

The implications of this research extend beyond academia, as the findings provide valuable guidance for policymakers and governmental entities responsible for urban development and public infrastructure. Particularly, the government can adopt the research outcomes presented in this thesis to initiate sustainable practices within public schools, where financial constraints often hinder the implementation of environmental initiatives. By transforming school rooftops into green spaces, the government can simultaneously improve the quality of educational facilities and contribute to the larger goal of creating more sustainable cities.

It is essential to acknowledge the limitations and challenges encountered throughout the course of this study. The unprecedented spread of COVID-19 and the catastrophic explosion at the Beirut port in August of 2020 significantly disrupted the research process. The closure of schools and the subsequent restriction of access to facilities prevented the completion of detailed site visits. Consequently, certain data gaps had to be filled by collating information from diverse resources, potentially introducing inherent biases or limitations in the analysis. Future research endeavors should strive to overcome these obstacles by conducting more extensive on-site investigations and collaborating closely with educational institutions to gather accurate and comprehensive data.

Furthermore, this research highlights the significance of wind analysis as a crucial element in the design and implementation of green rooftops. The findings emphasize the role of wind in influencing the selection of appropriate vegetation and design considerations to optimize wind velocity for plant growth or redirect it to minimize potential harm. This aspect adds a valuable dimension to the existing literature on green rooftops and expands our understanding of the interplay between environmental factors and rooftop greening.

Looking ahead, this thesis suggests several promising avenues for future research. One particularly compelling direction is the application of a hydroponic system, a third type of green rooftop, on university rooftops. This system, requiring more maintenance and specialized expertise, can provide a valuable opportunity to explore the feasibility of integrating advanced cultivation methods in educational settings. Investigating the benefits, challenges, and potential educational outcomes of hydroponic green rooftops would contribute to the growing body of knowledge on innovative approaches to urban agriculture and sustainable practices within educational institutions.

In conclusion, this thesis underscores the significance of sustainable rooftops in public schools as a means to enhance environmental sustainability, improve the quality of the built environment, and create valuable spaces for various stakeholders within the community. By integrating greenery into urban rooftops.

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