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Eiad Alsayadi The influence of urban form on noise exposure of buildings

Universidade do Minho
Escola de Engenharia

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Master Dissertation
International Master in Sustainable Built Environment

Supervisor
Prof. Doctor Lígia Torres Silva

April, 2016

Dedication

I dedicate this Master dissertation firstly to my parents; Ola Habbal and Mounzer Alsayadi for their love and great support through my entire life, and to my siblings; Anas, Noura and Ahmad for their support, love and for the laughs we shared.

Secondly to my country Syria and all the martyrs of the Dignity Revolution of Syria who paid their lives for our freedom.

Lastly, to all my friends, especially: Nahed, Mariam and Ahmad for their great help.

ACKNOWLEDGEMENT

I would first like to thank my supervisor **Prof. Lígia Torres Silva** of the **Department of Civil Engineering** at **University of Minho**. The door to **Prof. Silva** office was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this dissertation to be my own work, but steered me in the right direction whenever she thought I needed it.

Also, I would like to thank my professors in the **Sustainable Built Environment International Master** for their dedication through the learning process of this master.

I am also grateful for the **Department of Civil Engineering** members for their help and support.

I wish to express my sincere thanks for **President Jorge Sampaio** and **Doctor Helena Barroco** for their continuous encouragement for me and my colleagues.

I take this opportunity to express gratitude to the entire **Global Platform for Syrian Student** for their help and work to provide this opportunity for us to complete our studies.

I also place on record, my sense of gratitude to one and all, who directly or indirectly have lent their hand in this venture.

Eiad Alsayadi

ABSTRACT

People live in urban areas, they engage in various activities of life such as (housing, work, leisure, education, etc.) in an interactive way. The growth of population rates, density and the industrial development are all factors that affect the urban form and its growth, which in turn affects the environmental factors, such as the air quality and the noise pollution. Noise is the second most dangerous environmental pollutants on human life as it affects one's health and daily habits, it reaches people by its propagation, where the propagation of noise varies in accordance with the urban forms. This study will provide a new perspective to understand the environmental noise problems in the urban spaces, in terms of the relation between the urban noise and the urban forms, through studying urban indicators at various urban forms, and predicting the propagation of noise on the buildings facades of these forms during the day using a noise prediction method. Then comparing the effects of noise propagation in the selected urban forms, which will help to choose the best scenarios for urban forms and buildings facades with less exposure to noise. Also, it will allow the creation of several scenarios and the prediction of the noise levels generated from these scenarios at the design stage, in order to minimize the effects of noise exposure on buildings facades in advance.

Keywords: Development of Damascus city, Urban form, Urban indicators, Noise, Noise indicators, Noise prediction, CadnaA.

RESUMO (ABSTRACT IN PORTUGUESE)

O crescimento da população, a densidade e o desenvolvimento industrial são fatores que afetam a forma urbana e seu crescimento; que por sua vez afetam os fatores ambientais: qualidade do ar pela dispersão de poluentes através do tecido urbano e claro, o ruído através da propagação deste no meio urbano. O ruído, é o segundo poluente ambiental mais perigoso para os seres humanos, afeta o dia-a-dia da população, e a propagação de ruído varia de acordo com a forma urbana. Este documento fornece uma perspectiva para compreender este problema através do estudo de indicadores urbanos e o estudo da propagação de ruído nas fachadas edifícios durante o período do dia. O presente trabalho pretende, abordar a problemática do ambiente urbano, enquanto espaço de interação de formas urbanas e ruído urbano. Essa interação pretende ser monitorizada por indicadores urbanos, comparando os efeitos da propagação de ruído, em formas urbanas tipo selecionadas da cidade de Damasco na Siria. Foram utilizados cinco indicadores de forma urbana e recorreu-se ao modelo de previsão de ruído (NMPB96) para prever a propagação do ruído, permitindo desenvolver estudos de ruído em fachadas (Ld, Nível de ruído do período diurno), que resultou em cores associadas a classes de ruído. O estudo permitiu, com a criação de diferentes cenários, antever, já em fase de projeto, as fachadas expostas a um nível de ruído mais elevado, podendo minimizar assim antecipadamente os efeitos do ruído nessas fachadas.

Palavras chave: Desenvolvimento da cidade de Damasco, A forma urbana, Os indicadores urbanos, O ruído urbano.

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CHAPTER 1

1 INTRODUCTION

Urban form used to be defined as a representation of direct relationship in a specific piece of land between outer space and its content of buildings and other elements, which means that it is an entire city entity (physical environment, diverse activities and the formation of spatial structure). In order to understand this definition of urban form, the relationship between the outer space and its contents must be studied and analysed (Oliveira and Silva, 2011).

The large-scale urban form can be divided into tangible forms and intangible forms, the tangible forms includes the distribution in urban areas, the use of external urban land engineering in different ways within the pattern of regional city differentiation, spatial organization of architecture and landscapes, roads and transport in urban areas and so on. The intangible forms refers to all social and cultural activities and other forms of the city of intangible elements of the spatial distribution. Therefore, the urban design directly correlates with population growth and density, street layout and various transportation modes, according to Chenowth (2008) “Environmental planning holds the key to determine the pattern and the extent of urban growth”.

With the growing acceptance of the concept of sustainability and friendship environment, it was necessary for the researchers and organizations to focus in renewing and creating new issues of urban forms that commensurate with this concept (Conzen, 2001). According to Lotto (2008), the global urban system has been divided into three sub-systems: built and settlement system, environmental and green system, mobility and accessibility system.

Looking forward to a sustainable urban form has become a necessity to achieve a better life in terms of economic, social justice, and reducing environmental degradation (Breheny, 1992, Roo and Miller, 2000). According to Farr (2007), sustainable urban planning is to apply the theory of sustainability and flexibility in the design of management and operation of the community. Also, Farr linked the sustainable urban planning with what is known as environmental cities, which aims specifically to make eco-friendly cities.

Most city dwellers consider that excess noise occupies second place immediately after the contamination of water among the issues of concern (Preacher, 2001). According to Gomes (2008) “The concept of the sustainable city, synonymous of modernity and development, corresponds to healthier cities, with less noise, less contamination, more presence of vegetation, within other facts that extend towards a more social, economical and environmental quality of life for its citizens”.

The noise is considered as one of the most serious diseases of this age, it is defined as unwanted sound to hear, it sounds ragged senseless and significantly affect the comfort, productivity, and health of humans. The noise pollution is increasing day after day, especially in densely populated urban areas (Alkassem, 2013).

Rules and regulations existed in old times such as in ancient Rome, there were set of rules in night-time for the wagons that hit the stone pavement because it disturbed Romans while they were asleep. Also, in medieval Europe, they forbade horse riding during the night in some cities so they will not be disturbed in their sleep. Now the cost of modernization, the huge amount of cars, railroads, and airplanes are causing noise pollution all across the world (WHO, 1999). The commission of the European communities in 1996 released the Green Paper on Future Noise Policy, it was the first step to set a future policy for noise, also, it was an attempt to develop information of noise sources and future actions to reduce it (European Commission, 1996). Later the World Health Organization (WHO), the task force held a meeting in April 1999 and released a document on the guidelines for community noise in Europe declaring that about 40% of the population in European Union countries are exposed to more than 55dB of noise level during daytime due to the exposure of traffic noise. The same document states that more than 30% are exposed to noise levels at the night-time. These statistics were the start point to provide the knowledge and evaluating of the danger and the harmful effects of noise levels on human health aiming to protect the public from it (WHO, 1999).

In 2002, the European Commission released the Environmental Noise Directive 2002/49/EC on the assessment and management of environmental noise, they focused on three action areas; determining the exposure of environmental noise, making the information collected on environmental noise public and reducing the environmental noise in where it is necessary and preserving its level where it is good. It applies to the open areas and does not apply on noises from indoor such as domestic activities (END, 2002).

According to European Environment Agency report No10/2014, Noise pollution causes harmful damage to human health such as annoyance, sleep disturbance that leads to reduced performance, fatigue, depression and even insomnia, physiological effects and mental health effects. Also, some studies on humans have shown that noise increases heart rate that leads to aging of the heart, blood pressure, vasoconstriction and it releases stress hormone including adrenaline and noradrenaline as shown in Figure (1.1) (EEA, 2014).

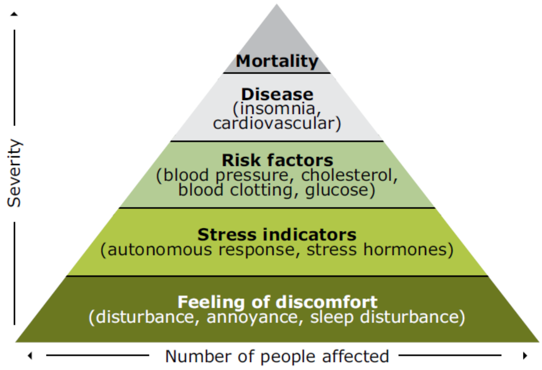

Figure 1.1 Pyramid of noise effects

Source: (EEA, 2014)

In developing countries, there was not enough care for the damages of noise pollution even with increasing awareness of environmental problems, however, noise was increased especially with overcrowdings of means of transportation, nonetheless the rules that limits from noise are unfamiliar for most of the people and rarely applied. Syria is not excluded from this, as it is a developing country that has population growth and an increasing number of means of transportation and traffic, noise pollution is all over the cities and urban communities with very high levels of noise. Late studies have shown that most neighborhoods in old Damascus have an average noise level between 70dB and 80dB, and these high levels appeared in some residential areas in Aleppo city as well, where the noise levels should not be more than 55 dB in the daytime. Even the differences in noise levels could reach 30dB caused by the sudden sounds of cars horns, motorbikes trucks, buses…etc. (Meslmani, 2008).

According to Pereira (1974), urban form is affected by the formation of the site, blocks implementation, topography, wind velocity and direction, and the type of soil and subsoil, finally, all comes as a landscape configuration. Therefore, the different locations of buildings in a piece of land from a source of noise gives a different impact of noise levels on the buildings facades and consequently on residents of these buildings. Thus, there is a need to predict the noise exposure levels of buildings in order to minimise these levels, by knowing which is the best distribution of building on a piece of land or which is the best urban form with fewer noise levels.

This study will evaluate the propagation of noise levels on buildings facades depending on their distribution on site, in order to address the environmental noise problems in the urban spaces according to the relation between the urban noise and the urban form. By firstly providing different urban forms and applying some urban indicators on them, then exposing those urban forms to several scenarios of noise sources, afterwards comparing the behaviours of the noise propagation on the chosen urban forms. Using the noise prediction method 'NMPB 2008' and the CadnaA software to translate the noise behaviour into clear numbers and graphs depending on the noise levels. According to Thomson (1883) ''When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.''.

This study will allow knowing which urban form buildings facades are exposed to high noise levels and which ones are exposed to low noise levels. In this way, it will be possible to minimize the effects of noise on facades in advance, by the creation of several scenarios and the prediction of the noise levels generated from these scenarios at the design stage in terms of the buildings mass properties, the distribution of buildings, and the configuration of the built form.

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CHAPTER 2

2 URBAN FORM

2.1 Definition of urban form

According to Anderson, et al. (1996) "Urban form may be defined as the spatial configuration of fixed elements within a metropolitan region". It represents a direct relationship in a specific piece of land between the outer space and its content of buildings and other elements (Oliveira, M. and Silva, L., 2011). In other words, it means that it is an entire city entities (physical environment, diverse activities and the formation of spatial structure). The large-scale urban form can be divided into tangible forms and intangible forms, the tangible forms includes the distribution in urban areas, the use of external urban land engineering in different ways within the pattern of regional city differentiation, spatial organization of architecture and landscapes, roads and transport in urban areas and so on. The intangible forms refers to all social and cultural activities and other forms of the city of intangible elements of the spatial distribution (Oliveira, 2011). Therefore, the urban design directly correlates with population growth and density, street layout and the various transportation modes, according to Chenowth (2008) "Environmental planning holds the key to determining the pattern and extent of urban growth".

2.2 Urban form elements

According to Anderson, et al. (1996) urban form consist of various tangible elements and intangible elements including size, shape, density, land uses, building types, urban block layout and distribution of green space, as shown in Figure (2.1).

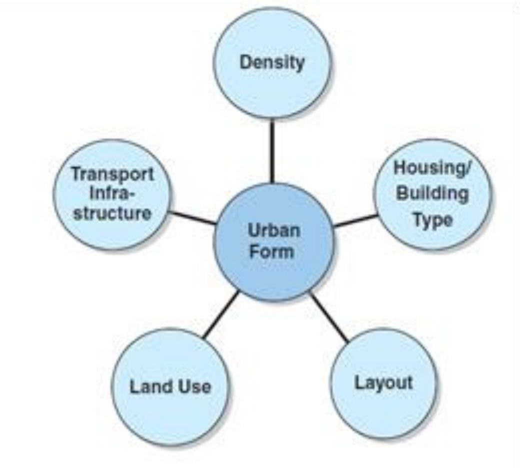


Figure 2.1 Elements of urban form
Source: **(Anderson, et al., 1996)**

2.2.1 Density

Density is the measurement of the number of persons in a specific living area. It is connected to the dimension that depends on the characteristics of the individual, thus, it may be different from one resident to another (Churchman, 1999). Also depends on the cultural dimension that's may differ from one country rules to another. Density is linked to other elements of urban form such as the management of social environment: like high building with apartments and flats are considered to be of high density, and the detached and semi-detached houses are considered to be of low density. It is also related to land uses and patterns of accessibility especially within an area of urban transport. Thus, it is used as a tool to calculate transport infrastructure, and the probability of defined land uses especially in urban design and construction (Dempsy N., et al., 2010).

2.2.2 Land Use

Land use term, in general, represents the different functions within an environment. However in urban design land use is only residential, but any area to be active and functional needs infrastructure. Land use is important to evaluate the efficiency of a city because it influences the urban form especially related to sustainable urban form when talking about green spaces (Dempsy N., et al., 2010). In the infrastructure, there are some undesired land uses such as airports, landfills and prisons (Grant, 2002). An essential element in land use in any neighbourhood is the availability of services, however, it depends on the demands of each population so it varies from one neighbourhood to another (Urban Task Force, 1999). It is also a dynamic pattern as it is subjected to real estate influences.

2.2.3 Accessibility and transport infrastructure

The concept of accessibility it does not only depend on the distance, it depends on many factors such as; the locations that individual is tended to go, the transport system connections and how the individual planning to use it, and lastly the facilities that interest the individuals (Liu S., Zhu X., 2004). One of the keys of accessibility is the connection between home and city centre, and between what is reachable and available within a walking distance. Thus, it related to the transport infrastructure, the way it is distributed in the neighbourhoods and how it connects the individuals outside their local areas (Talen, 2003). Also it is connected to land use and urban layout, since streets are one of the land use, and are an element of urban layout.

2.2.4 Urban Layout

The layout is the spatial management of elements like streets, buildings and blocks, like in a grid and street patterns (Dempsy N., et al., 2010). Today's layouts of the cities are mostly results of the historical development, planning and regulations through time. The management of the layout has an important influence on city functionality, configuration of street networks, block sizes and location of the city. Urban layout controls accesses and the movement of pedestrians and it could influence other aspects of urban form like land use and density whether it is permeable or not (Hillier B., and Hanson J., 1984, Hillier, 1996).

2.2.5 Housing and building characteristics

The characteristics of housing and building are important to everyday living, it doesn't only depend on density; like the experience of people who lives in a low density area of detached, or semi-detached houses that has front and back yards, is totally different from the experience of people who lives in high density city of apartment dwellers. However, it also depends on the type, age, height, orientation and daylight exposure of the residence (Mardaljevic, 2005).

2.3 Urban form development

Until quite recently, the city was seen as a set of distributed land uses on districts, linked by a network of certain roads. This concept has evolved to absorb the urban city as a spatial frame where the population lives from birth until death, and engage in various activities of life such as (housing, work, leisure, education, etc.) in an interactive way. That was admitted to provide new dimensions in order to face the needs and the problems arising from the dynamics of the society and its development, depending on studies that comprehend the reality of the city and the factors affecting it in order to reach efficient formats in providing what is necessary to live, work, leisure and learn to give comfort and happiness to the people of the city. Therefore, the process of urban planning according to Saab (2009) became to this following dimensions:

1. Urban planning is a comprehensive study, systematic, sequential, analytical, artistic and practical.
2. Urban planning is an important practice for the social economy to humans.
3. Urban planning includes balancing between working parts and their relationship with everything, which means is a balancing contract between things and work force.
4. Urban planning includes implementation of plans and the recognition of the human scientific abilities, as well as the natural and social conditions of the environment in order to accomplish an organized set of goals for the planning.
5. Urban planning is determined according to the state policy and applied by the force of main planning law.
6. Urban planning is a process done according to certain time periods, including short, medium and long term, which is the allotted time for the implementation of the plan, as well as being within geographical areas including; Local-planning, State-planning, Regional planning and Universal-planning.

2.3.1 Sustainable urban form

Sustainable development concept was first popularized in the paper of Our Common Future by (WCED, 1987), stating that the development needs to be sustainable so it fulfills the present requirements and meets the needs of the future generations without compromising it. There has been a lot of debates concerning this point and concerning issues linked to population, biodiversity, industry, energy consumption, global warming, pollution, equity in access to resources and urbanism

(Breheny, 1995). In 2001, the Us Environmental Protection Agency stated that urban form directly affects inhabitants, ecosystems, endangered species and water quality through fragmentation of inhabitants, consumption of land and replacing nature cover with impervious surfaces. As it also affects travel behavior, which in its turn it affects air quality, lands, global climate and noise pollution (Cervero, 1998). The debates on sustainable urban form have become greater with time, many designers and architects have tried to achieve the most sustainable urban form. There are many different urban forms, each one has its own contribution to sustainability such as; compact cities that has high density and compactness, eco-city that approaches the environmental management through urban greening, cultural diversity, solar design and urban containment that emphasizes policies of compactness. However according to design concept of sustainable urban form, the ideal urban form has high density, adequate diversity, compact with mixed land uses, sustainable transportation, greening, and passive solar energy all to reduce pollution, automobile use, waste, energy consumption, and to reserve eco-systems and livable community-oriented human environment (Jabreen, 2006).

2.3.2 The urban development of Damascus city

Damascus, the capital of Syria Arab Republic located in the southeast of the country, is considered to be the oldest continuously inhabited city in the world. The old Damascus has a statute of World Heritage Site. The city went through many formation and city development since the Hellenic era through Byzantine, Ottoman and Umayyad till Mandate and until now.

Around 3000 BC, the early urban structure of Damascus was set, the walls of the city were built around the existing area, the Hellenic era around (334-146 BC) was the first to plan the city with geometric patterns and straight lines, Figure (2.3) (Wifstrand, 2009). As shown in Figure (2.2) the Greek temple of Jupiter is now the site of Umayyad Mosque (Lababedi, 2008).

In 64 BC Syria was one of the provenances of the Roman Empire and they continued developing the existing cities and creating new ones after the Greeks. Figure (2.4)

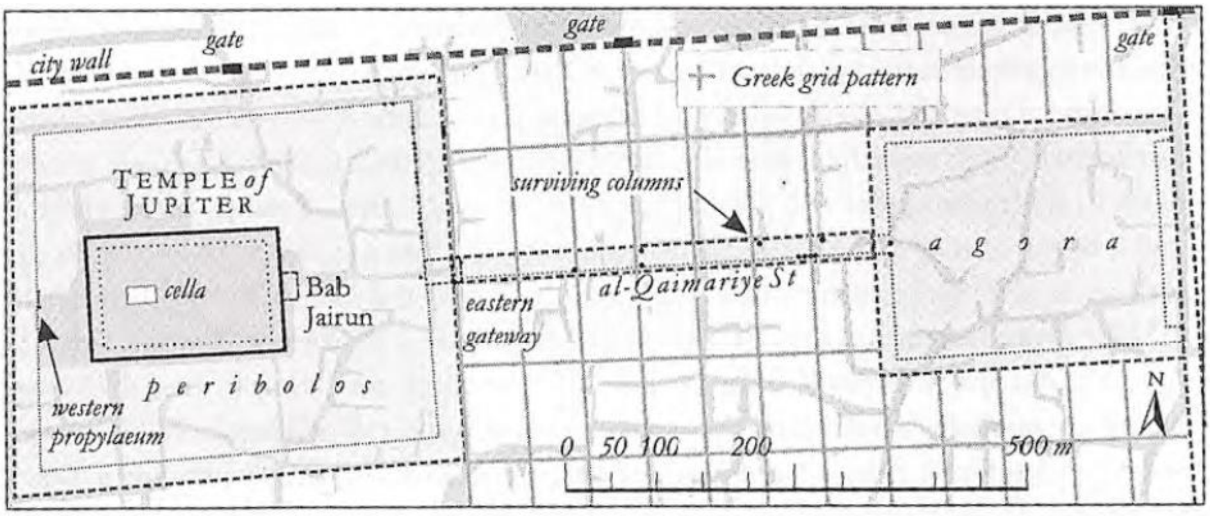


Figure 2.2 Temple of Jupiter

Source: **(Lababedi, 2008)**

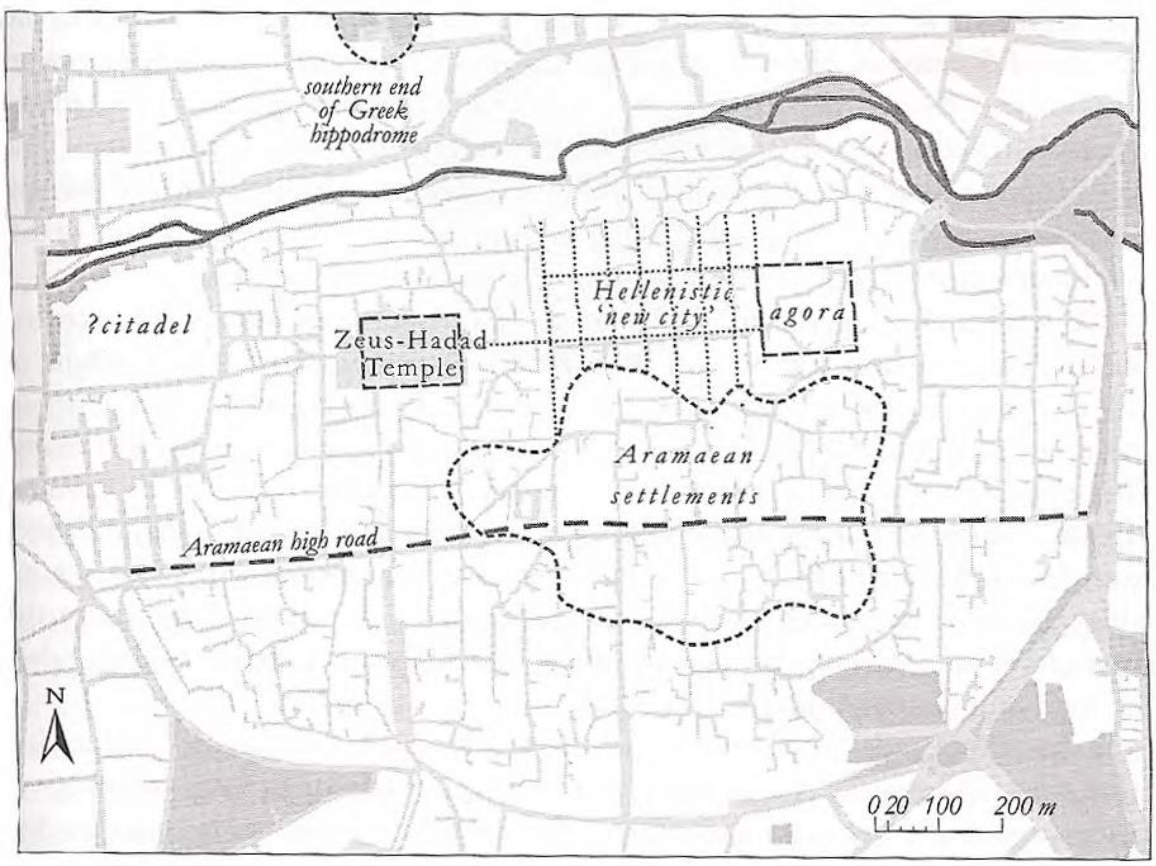


Figure 2.3 Hellenistic Damascus

Source: **(Wifstrand, 2009)**

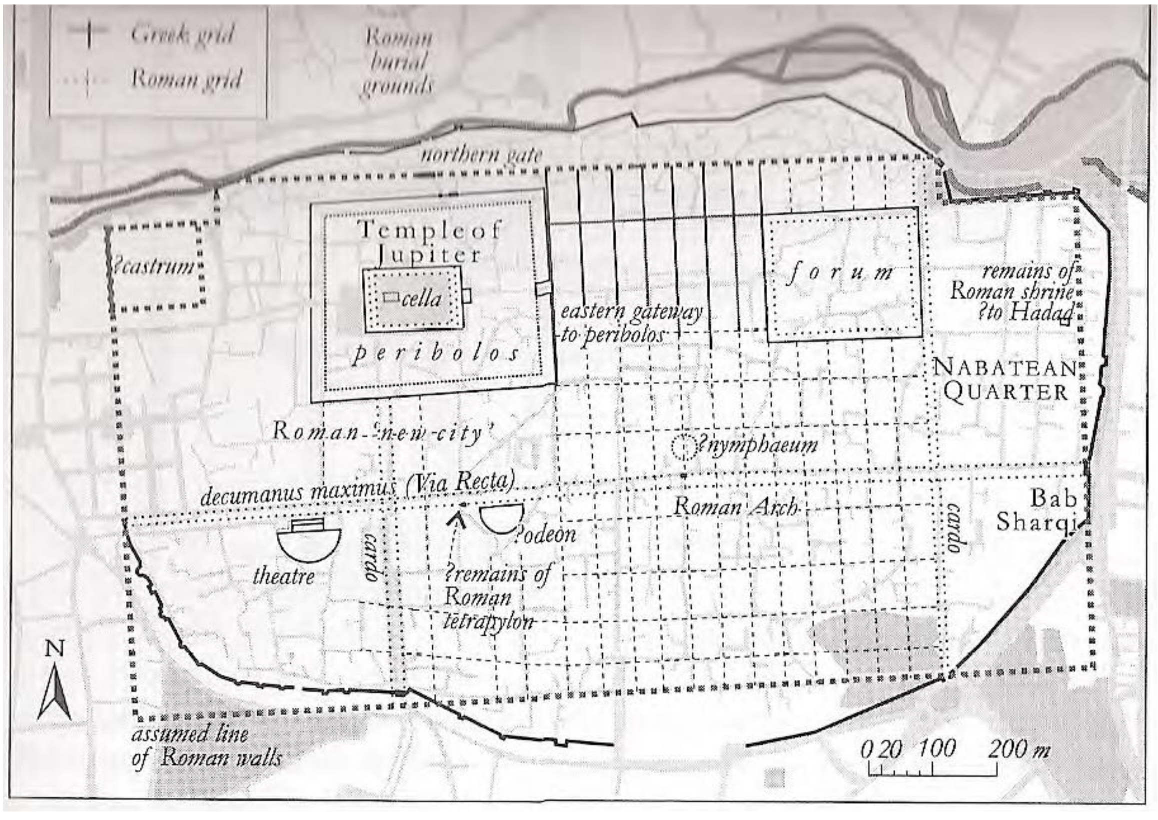


Figure 2.4 Roman Damascus

Source: **(Wifstrand, 2009)**

Old Damascus that is world heritage now is almost the same size of Roman Damascus, the Romans expanded the temple of Jupiter, the grid system, Figure (2.4), and developed the first water pipes which can still be seen in today's Qanawat district (Burns, 2005). The roman control ceased in 636 AD and then Damascus fall in the hands of Byzantine, who were poor in administrative they gave the church and house owners the freedom to expand their properties and the temple of Jupiter was rebuilt to Cathedral of St. John the Baptist (Wifstrand, 2009).

Umayyad gain control over the city and the Umayyad Mosque was built in the place of the church of St. John. During the Umayyad era the city grew in a random way given to the importance of privet property in Islam, people were free to expand their properties as long as their neighbors were not offended, thus came the result of narrow streets. There was no actual development of the city like in the times of the Roman or Greeks, as what was important is the city protected by walls surrounding it and inside having a mosque and a supply of running water. As Bianca (2000) describes, traditional Islamic cities followed an "organic pattern of growth". As shown in the Figure (2.5).

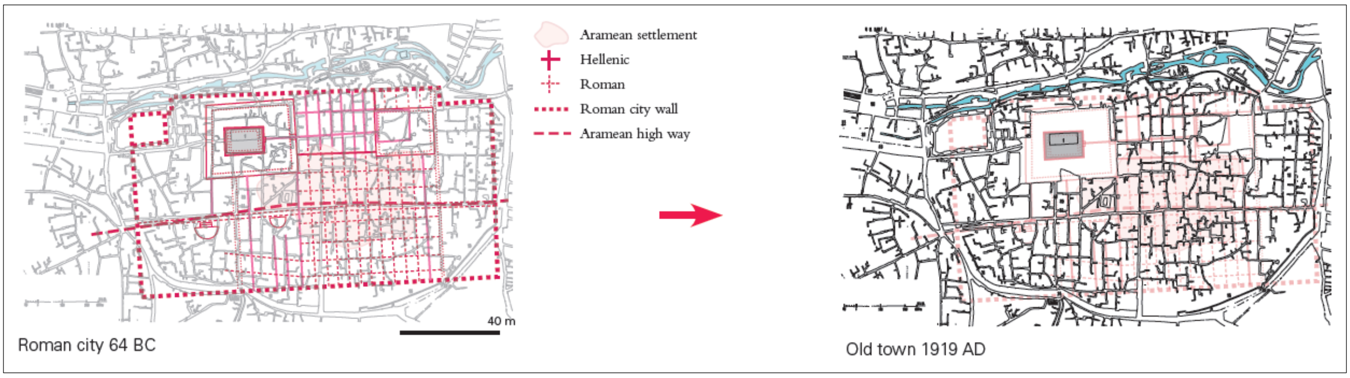


Figure 2.5 Damascus growth
Source: (Wifstrand, 2009)

Later in the Ottoman era in the late 19th century, Damascus grew crucially as it became a meeting point for pilgrims and caravans. It expanded outside the walls of old Damascus filling the left bank of the river, spreading south and north with new suburbs, depending on three principles; widening of streets, designing the new suburbs with geometric rules, and constructing with stone instead of wood, all this due to western influences (Lababedi, 2008). Figure (2.6) shows the historical development of Damascus through time until the 1960s.

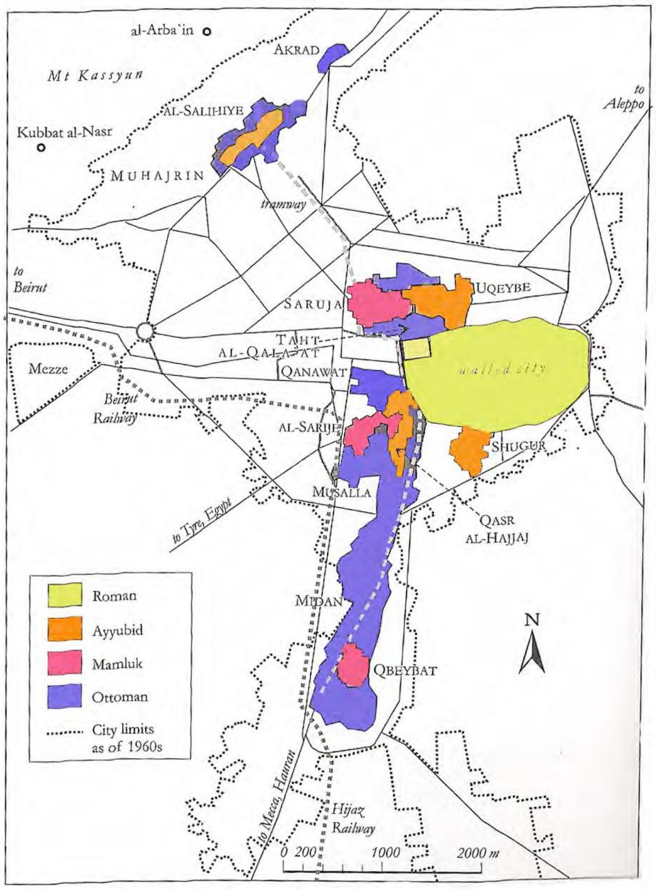


Figure 2.6 Damascus - Historical development

Source: **(AlQattan, 2002)**

Figure 2.7 Al-Muhajirin plan

Source: **(Arnaud, 2006)**

Al-Muhajirin, in Figure (2.7), was the first suburb built for refugees fleeing massacres. As Damascus will have more many in the following years and most of them will not be planned.

The French mandate began after the First World War, early 19th century, they continued the urban development of Damascus ignoring traditions and needs of the locals. The first master plan by the French urban designer Rene Danger working along with Michel Ecochard, they proposed a ring road around the old city to avoid traffic problems of the city center axis that cut through it, also managing a functional zoning of the city, as shown in the Figures (2.8-2.9). The plan was later adopted in the 1960s and completed in 1994.

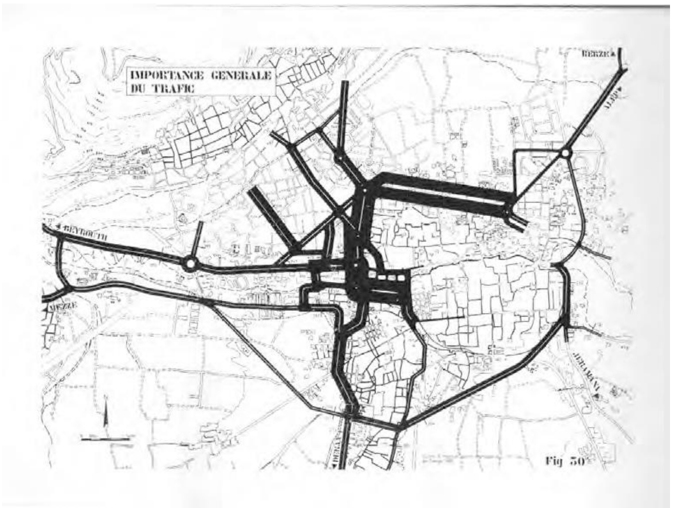


Figure 2.8 Danger-Ecochard Original Central Road System 1935
Source: **(Lababedi, 2008)**

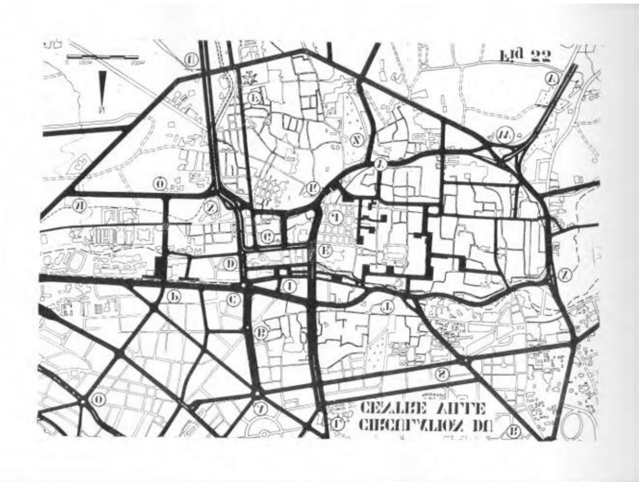


Figure 2.9 Danger-Ecochard Original Central Road System 1935
Source: **(Lababedi, 2008)**

In 1963, the Socialist Party took control in Syria, so Damascus went over the influence of contemporary planning and architecture, the district Al-Mazzah - Figure (2.10) - was one of the new suburbs under this influence and then was presented the urban form to Syria with the help of the Japanese planner Banshoya.

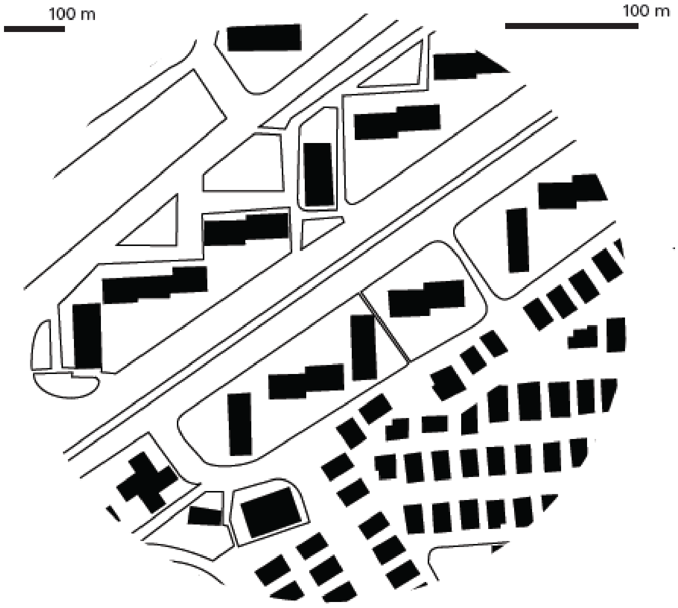


Figure 2.10 Al-Mazzah- introducing urban form
Source: **(Wifstrand, 2009)**

2.4 Syrian urban forms

The concept between traditional urban form of Arab cities and modern urban form is different in many ways. The western model follows a number of subdivision approaches in managing any land, by creating smaller pieces of place from a larger space. While the traditional Arab urban form is mainly an organic accumulative formation of portions (Kiet, 2001) illustrated in Figure (2.11). Since Damascus was under the Islamic rule, where in Islam, the family is considered to be important and needs its private space, this level of privacy can be seen clearly in the formation of the urban fabric of the residential part of the city. “House” which in Arabic is “Bait” means in the physical way a site and a social unit or family. (Lababedi, 2008).

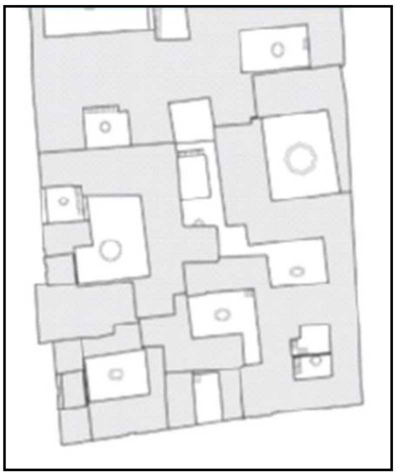


Figure 2.11 traditional Arab urban form.
Source: **(Lababedi, 2008)**

The Damascene house characterized by being away from streets noise, environmental pollution and a safe place for its inhabitants. The entrance starts from a small corridor that hides the house from pedestrians and wind. The house is constituted of two floors with a set of rooms surrounding the courtyard that has green and water elements. The main room, which called Al-Iwan, is a room opened to the courtyard and elevated from the floor, which is the room for gathering weather with friends or family. Mostly all the rooms are with high ceilings the ones on the ground floor is for the summer as it is cooler, and the ones on the top are for winter as they get more. The Damascene houses are mostly designed to get the sun from three directions and especially the courtyard which is the core of the house is mostly oriented north-south to maximize the solar radiation and for a comfortable setting in hot summers. In the Figure (2.12) below is the plan of Damascus house.

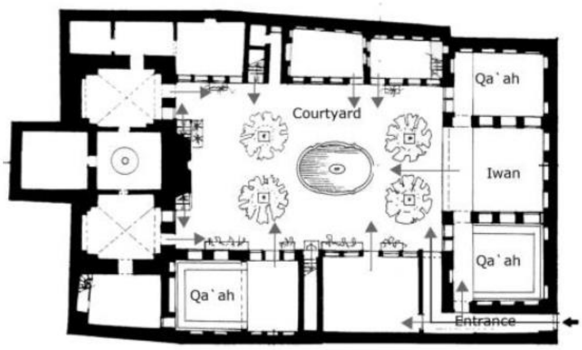


Figure 2.12 plan of a Damascene House
Source: (Amro, et al., 2015)

As mentioned before, later in the late 19th century beginning the 20th century Damascus under the ottoman rule and then the French mandate the urban city fabric has changed to the western model. The creation of suburbs outside the city walls was planned, the residential area had no more privacy as before with the narrow streets as they became wider with tree lines, the disappearance of accumulative units and spaces with definitive patches and the house has no courtyard core anymore. The suburbs were built with the modern western style, classical and Rococo style buildings in the hands of French and Italian architects became inhabitant with wealthy families of traders such as Al-Salhia neighborhood.

With the continuous growth of Damascus and under the socialist party the urban form entered Syria in many neighborhoods scattered around the city, organized in only a few small areas such as in Al-Mazzah district in the 1960s.

Figure (2.13) below illustrates how the urban form of Damascus has changed.

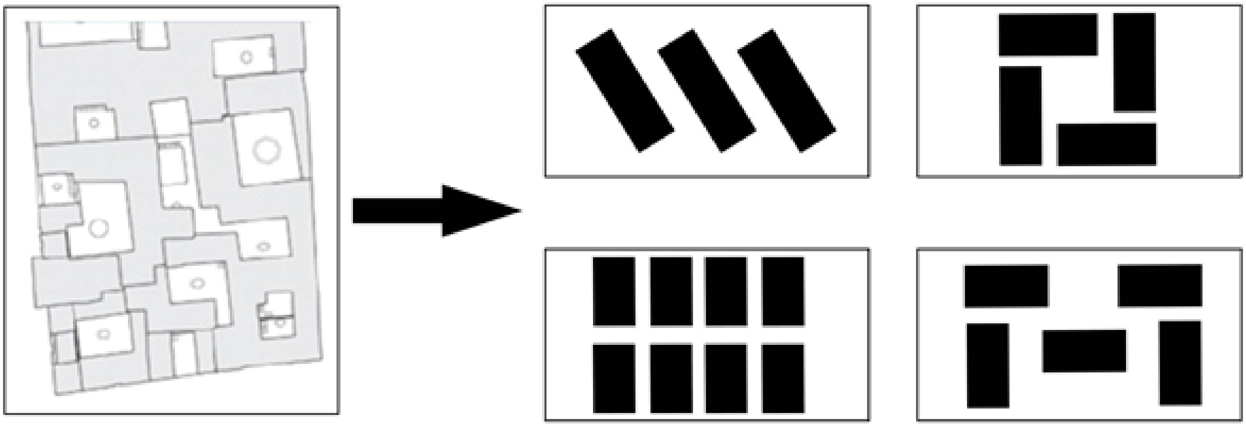
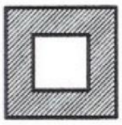


Figure 2.13 Development of Damascus urban forms
Source: **(Lababedi, 2008)**

2.5 Morphological classification:

The morphological classification is a tool that helps to indicate the morphological components, in order to limit its scope, and according to Pedro (2002) the criteria that are used in the morphological classification are as follows:

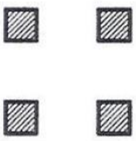
- Implementation form of a group of buildings
  - Closed implementation (buildings clearly bound out the outer space, the buildings interruption is in an equal distance or lower than the quarter of the total length of the exterior space perimeter).

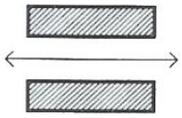
  - Linear implementation (the buildings only suggest the shape of the outer space, the buildings interrupt a higher distance of a fourth part and lower than the half of the total length of the exterior space perimeter).

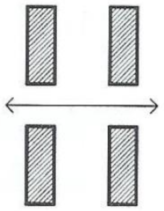
  - Punctuate implementation (buildings do not limit the outer space, the buildings interruption is in a higher distance of half of the total exterior space perimeter).

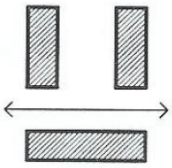
- Form of implementation of the building depending on streets:
  - Aligned implementation (implementation of building along the street).



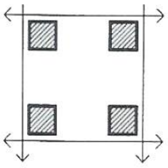
  - Unaligned implementation (a free implementation of buildings fairly with the streets).



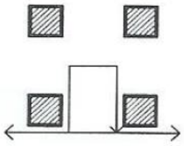
  - Mixed implementation (aligned and unaligned implementation).



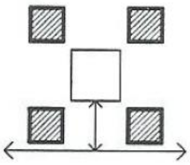
- Form of local road access:
  - Continues access



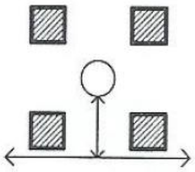
  - Ring access



  - Square access



  - Dead-lock access



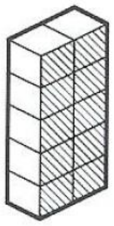
- Number of floors above the entrance level of buildings of close neighbourhood
  - Single-storey buildings (R/C to R/C +1 floor, or till 4,00m high)
  - Low-rise building (R/C + 2 to R/C + 3 floors, or till 9,00m high)
  - Medium-rise buildings (R/C + 4 to R/C + 9 floors, or till 28,00m high)
  - High-rise buildings (more than R/C + 9 floors, or more than 28,00 high)

- Number of dwellings in buildings of close neighbourhood
  - Single-family (one dwelling per building)

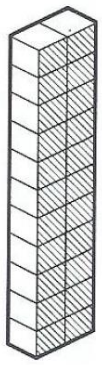
  - Duplex house (two dwellings per building)

  - Small multifamily (3 to 8 dwellings per building)

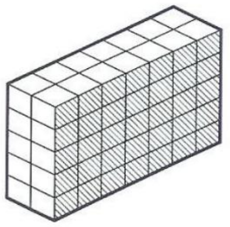
  - Medium multifamily (9 to 20 dwellings per building)



  - Big multi family (21 to 60 dwellings per building)



  - Very big multifamily (more than 60 dwellings per building)



2.6 Urban form indicators

In order to characterize urban form, especially with the growing interest in defining its real differences in an exact and detailed way, a lot of studies has been trying to define them and proposed a number of variable quantitative and indicators to characterize urban sprawl patterns using spatial experimental data from household level to country level (Galster, et al., 2001, Ewing, 1997, Ewing, et al., 2002, Wolman, et al., 2005, Song, et al., 2004 a, Song, et al., 2004 b).

The experimental measurements of sprawled urban growth patterns in these works helped to change the understanding from impressionistic disputes to a common concept and useful analysis of urban form (Galster, et al., 2001).

Ewing (1997) addressed the urban form indicators based on residential density, neighbourhood mix of homes, jobs and services, available open spaces and accessibility in terms of residential and street networks. Galster, et al. (2001) had proposed the most eight detailed dimensions of urban sprawl: density, continuity, concentration, clustering, centrality, unclarity, mixed land uses, and proximity. Moreover, Hasse, et al. (2003) had analysed urban sprawl at a very small level in a small piece of land for gaining an accurate result of urban growth pattern all in a small scale. Also Song, et al. (2004 a) considered some measurement to characterize urban form related with development density, land use mix, connectivity, and accessibility. Furthermore, Tsai (2005) used for knowing the degree of sprawl a set of various measurement that based on density, land use mix, centrality, and metropolitan size.

This study is going to present some indicators which have nature dimensions based on the studies above, they are urban indexes and spatial metrics, which can be applied on other patterns of various forms. These indicators are going to help in constitute a fundamental rule making the comparison between urban forms easier.

2.6.1 Urban indexes

Urban indexes are multipliers that allow measuring if the area of study is more amenable to live or less over time, and if the methods we use to manage urban amenity are working, through exchanging of possible data. Moreover, these indexes can be applied to an area, a reference surface, and to an intervention area with various scenarios (Oliveira, M. and Silva, L., 2011).

2.6.1.1 Occupation Index

Occupation index (P%), is an indicator that addresses whether the surface of urban sprawl is high or low, through the percentage of the implantation area of the total land area. The calculation of the occupation Index (P %) is presented by Equation 1:

$$P\% = \frac{A_{imp}}{A_t} \quad (1)$$

Where:

A_{imp}, is the area of implantation (m^2).
A_t, is the total land area (m^2).

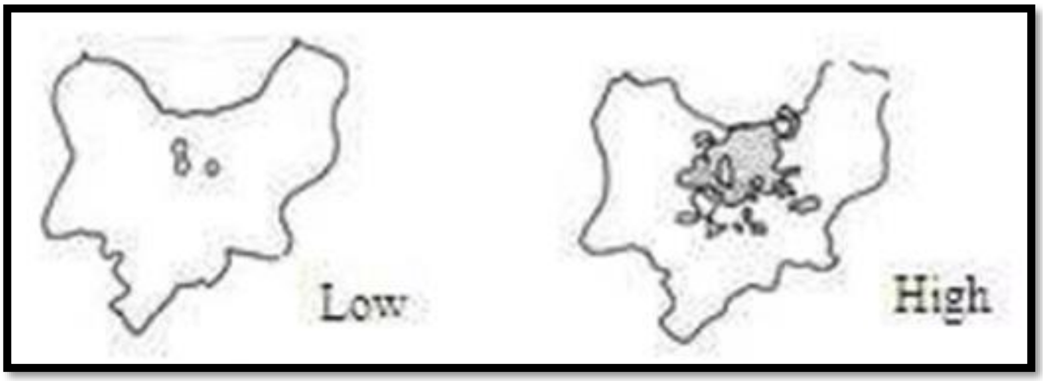


Figure 2.14 Illustration of occupation index (P%)

2.6.1.2 Volumetric Index

Volumetric index (Iv), is an indicator represent the space above the ground, surrounding and corresponding to all the buildings that exist on it. It is associated to the surface of implantation, the number of floors and floor height. All of these help to know whether the volume is high or low. The calculation of the volumetric index (Iv) is presented by Equation 2:

$$Iv = P \times N \times H \quad (2)$$

Where:
P, is the surface of implantation (m^2).
N, is the number of floors (-).
H, is the floor height (m).

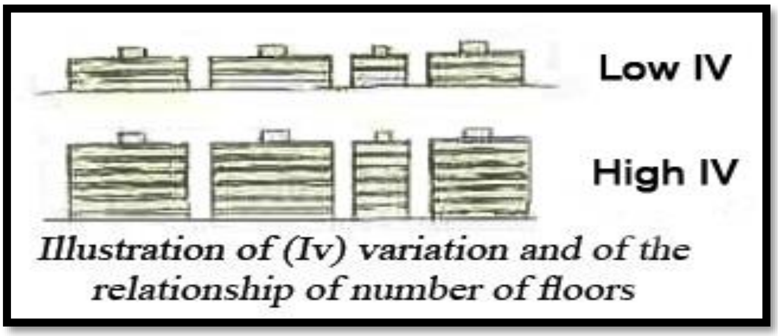


Figure 2.15 Illustration of variation and the relationship of number of floors (IV)

2.6.2 Spatial matrices

Spatial matrices expressed by a series of quantitative dimensions represent the physical characteristics and physical properties of the landscape and its components (Huang, et al., 2007). The used metrics in this study are going to present three dimensions of urban form: porosity index, compactness index, and form index.

2.6.2.1 Porosity index (ROS)

Porosity index is an indicator that measures the ratio of open space "holes" of an urban area (Galster, et al., 2004). In any urban area, the open space is essential for both the sustainability of cities and the residents comfort. This indicator measures the porosity of the total area of these "holes" compared to the total urban area. Equation 3 presents the calculation of the porosity index that is referred to it as the “ratio of open space” (ROS):

$$\text{ROS} = \frac{s'}{s} \times 100\% \quad (3)$$

Where:
s', is the total area of holes.
s, is the total urban area.

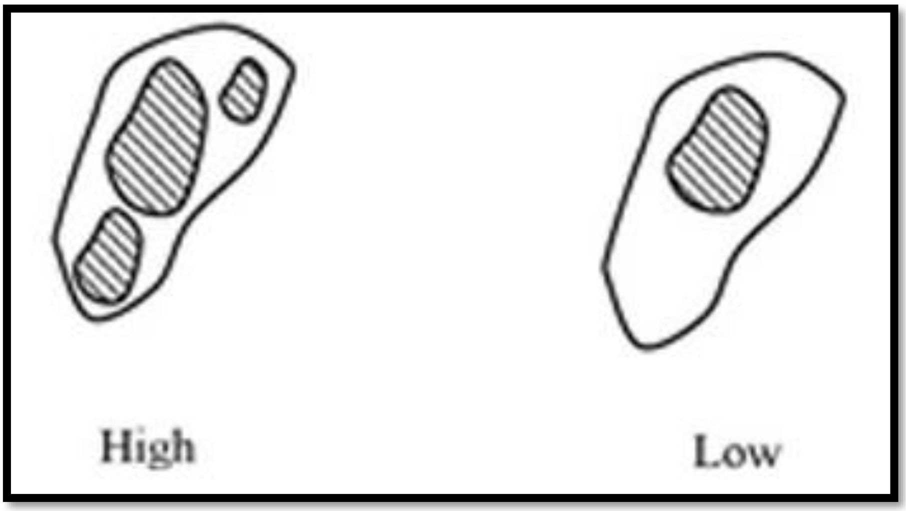


Figure 2.16 Illustration of Porosity index (ROX)

2.6.2.2 Compactness index (CI)

It is an index that measures the patch shape and measures the fragmentation of the entire urban land space. The area with more regular patch and a bigger number of patches will have the bigger CI value. It has been noticed that the largest patch usually represents the biggest part of the total urban area (Lia, et al., 2004). Equation 4 presents the calculation of the compactness index (CI):

$$\text{CI} = \frac{\sum i \frac{Pi}{pi}}{N^2} = \frac{\sum i \; 2\pi\sqrt{\frac{si}{\pi}}/pi}{N} \qquad (4)$$

Where:
si, is the patch area (m^2).
pi, is the patch perimeter (m).
Pi, is the surrounding radius (m).
N, is the total number of Patches (-).

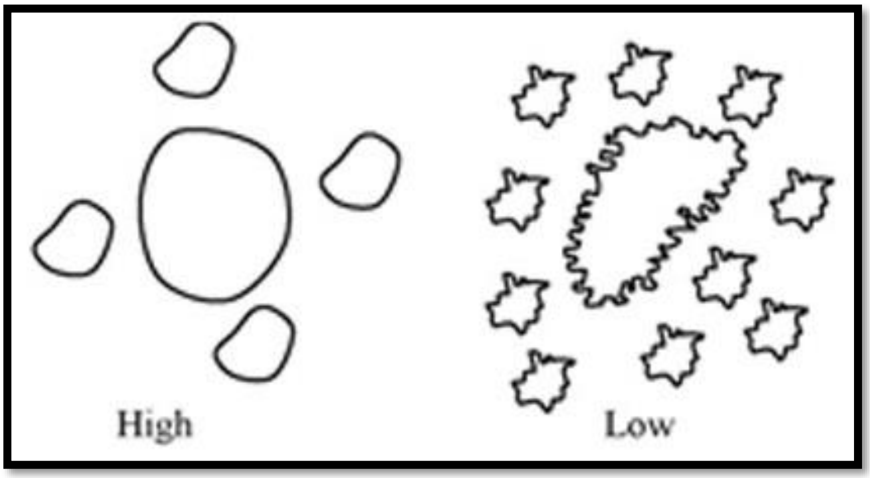


Figure 2.17 Illustration of Compactness index (CI)

2.6.2.3 Form index (Form)

The index form characterizes the complication of the perimeter of an urban area through the relationship between the perimeter and the area (Baass, 1981). Figure (2.18) represents the clarification of the forms regularity and complexity variation that influences the index (Form). Equation 5 presents the calculation of the form index (form):

$$\text{Form} = \sum_{i=1}^{n}\left(\left(\frac{ripi}{2ai}\right)\left(\frac{aj}{\sum_{j=1}^{n} aj}\right)\right) \qquad (5)$$

Where:

pi, is the patch perimeter (m).
ai, is the patch area (m^2).
aj, is the total area (m^2).
n, is the total number of Patches (-).

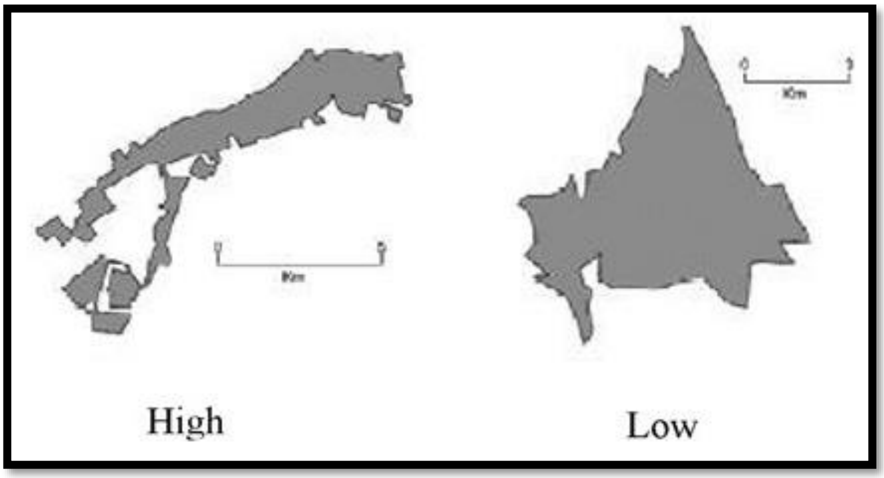


Figure 2.18 Illustration of Form index (Form)

CHAPTER 3

3 URBAN NOISE

3.1 Definition of noise

Noise can be defined as a disagreeable or undesired sound, it sounds ragged senseless. Noise considered as one of the most serious diseases of this age, and significantly affect the comfort, productivity, and health of humans. The noise pollution is increasing day after day, especially in densely populated urban areas (Alkassem, 2013).

The difference between noise and sound is greatly subjective, although they form the same phenomenon of atmosphere pressure vicissitudes about the average atmosphere pressure, but what consider sound to one person can be noise to someone else (Hansen, 2001). The perception of noise depends on people, time and locations, and it is understood as an unpleasant or annoying sound for humans, and that is why it is difficult to objectively determine the discomfort (Oliveira, M. and Silva, L., 2011).

3.2 Physics of noise (sound)

Sound (or noise) transfers into the elastic medium (e.g. air, water, solids) in a form of longitudinal waves because of pressure variations. Every sound tone has a specific wave and each wave is a series of compressions and rarefactions as illustrated by Figure (3.1) and characterized by its own amplitude, frequency, wavelength and velocity. Where the wavelength is the distance, where the pressure of the wave travels through one cycle, and the frequency is the number of vibrations that pass at a certain point per second, and represented by Hertz (Hz). The frequency and the wavelength have a linked relation as illustrated in Figure (3.2). Noise usually has a lot of frequencies combined together (Hansen, 2001).

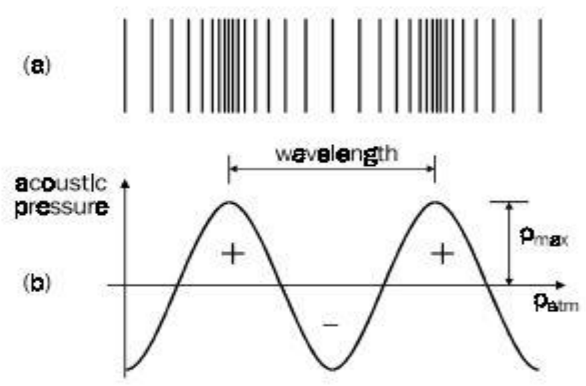


Figure 3.1 Illustration of sound wave.

(a) Compressions and rarefactions caused in the air by the sound wave.

(b) Graphic representation of pressure variations above and below atmospheric pressure.

Source: **(Hansen, 2001)**

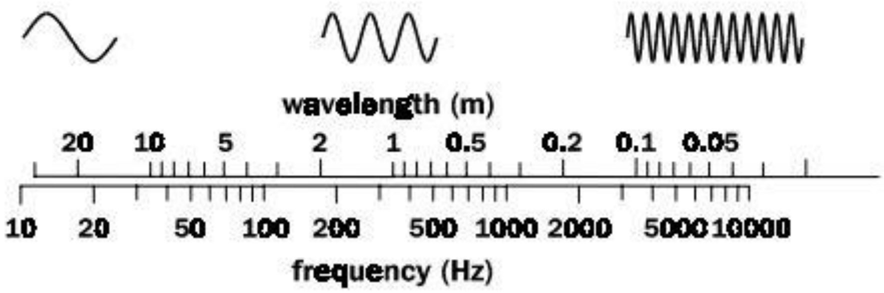


Figure 3.2 Wavelength in air versus frequency under normal conditions (Harris1991).

3.3 Noise measurement

Sound intensity measured in Decibel (dB), dB gives the lowest differences between any sound and another that human ear can hear. To make this more clearly, we can say that the human voice at a very low whisper is the least of sounds that the ear can catch and the sound of a get engine is the greatest. In term of power, the power generated from a get engine is 1000,000,000,000 times more than the power generated from whispering, and that is a huge difference. However, in terms of dB the whispering magnitude is not more than one decibel, and a sound 10 times more powerful than near total silence is 10 dB, a sound 100 times more powerful is 20 dB, a sound 1,000 times more powerful than near total silence is 30 dB, and so on. Measure of dB starts from zero where the voices are very dimness to 130 where they start causing pain, and voices usually divided in several degrees are: audible sounds, very calm sounds, disturbing sounds, and these disturbing voices are sounds that cause pain when it reaches the intensity of 130 dB (Al-Fefe, et al., 2007).

Noise measurement or (sound measurement) which it is called sound pressure level represents a logarithmic ratio of the measured sound pressure to the reference pressure which is the sound at the threshold of human hearing (Bhatia, 2014). Equation 6 presents the calculation of the sound pressure level:

$$L_p = 20 \times \log_{10} \frac{P_{meas}}{P_o} \quad (6)$$

Where:

L_p, is the sound level (dB).
P_{meas}, is the measured sound pressure (Pascal).
P_o, is the reference pressure ($P_{ref} = 20 \times 10^{-6}$ Pascal).

Since the human ear does not have the same sensitivity to noise, there are a different sensitivity scales for noise measurement. Those differences of sensitivity not only on the level of a sound, but also for the frequency of it which depend on the number of the sound wave vibrations. Where the human audible range of the frequency is between 20 Hz to 20kHz, and his sensitivity decreases at a frequency in 4000 Hz above ultrasonic and in 500 Hz below infrasound, as seen in Figure (3.3).

Figure 3.3 Range of frequency

Therefore, the measurement of hearing sensitivity should not be only for sound levels but also in term of frequency. Manufacturers have built different response curves during the development of sound level meters over the years and named them weighting scales A, B, C and D.

We use a scale to display these measurements of hearing sensitivity, which shows sound level (decibels dB) on the vertical axis, and frequency (hertz) on the horizontal axis, as shown in Figure (3.4).

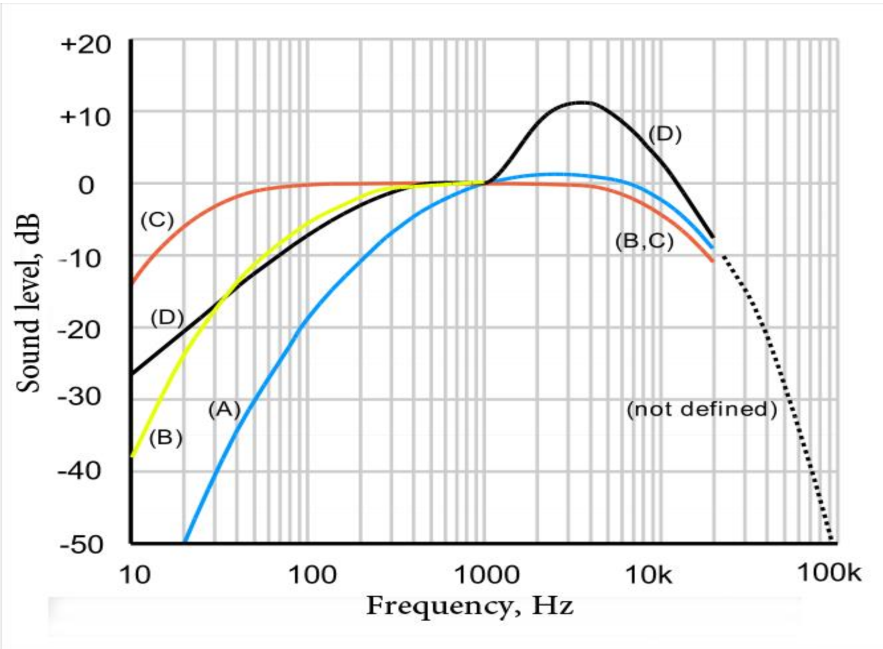


Figure 3.4 Illustration of A, B, C and D weighting curves

Source: **(Witt, 2005)**

A-Weighting is the most commonly used curve scale because it gives the best response of human ear to the frequency at low levels. In addition, it assesses potential damage risk of the ear and health effects of noise. The use of sound level set to the A-weighting frequency scale is mandatory for measurements of environmental and industrial noise, and it measures low-frequency noise that is similar to the human ear response. These noise measurements which are made with the A weighting scale are designated dBA (Witt, 2005).

3.4 Urban noise indicators

Decibel is not a unit of measurement of noise by itself, decibels are one of the ways to count large numbers. So to determine what ''Decibel'' means we need the both pieces of weighting value and sound spectra.

The sound pressure level (SPL) floats with time, so the sound which last over time cannot have a single SPL value. As it turns out there are several ways to describing the entire sound curve with a single number by using some frequent metrics (L_{eq},L_{max},L_{min}, and L_n).

L_{max}, and L_{min} are easy to understand, they are the highest and the lowest values shown on the sound level meter during the sound measurement. They refer the maximum and the minimum sound level to the equivalent, as seen in figure (3.5).

L_{eq}, The energy equivalent level or the equivalent continuous sound level is defined as the held constant sound pressure level over the whole given time. It results in the same energy as the actual variable sound levels.

Metrics L_{eq} and L_{max} are quite frequently used unlike L_{min}, but any way L_{min} is recorded alongside L_{eq} and L_{max}.

L_n, It is also methods that giving a single number from the measurement of sound level. However, it is not an actual level; the actual levels are numbers instead of the letter n. We can have any Ln value we want, but the most used metrics are L10, L50, and L90. Where L10 is the sound pressure level exceeded for 10% of the measurement time, L50 is the sound pressure level exceeded for 50% of the measurement time and it can be considered the median value, and L90 is the sound pressure level exceeded for 90% of the measurement time (Pagett, 2015).

All these indicators are shown in the chart below, in Figure (3.5).

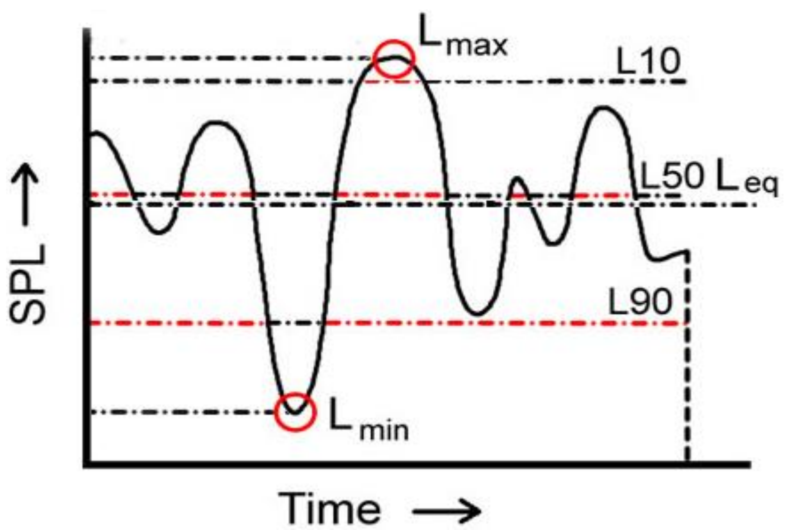


Figure 3.5 Ambient noise indicators

Source: **(Witt, 2005)**

To give the indicator Ln a better clarification, the Figure (3.6) below shows the lines without the sound pressure curve. The red section shows what would appear below the curve on the length of the lines, which are equal to the amount of the measurement time.

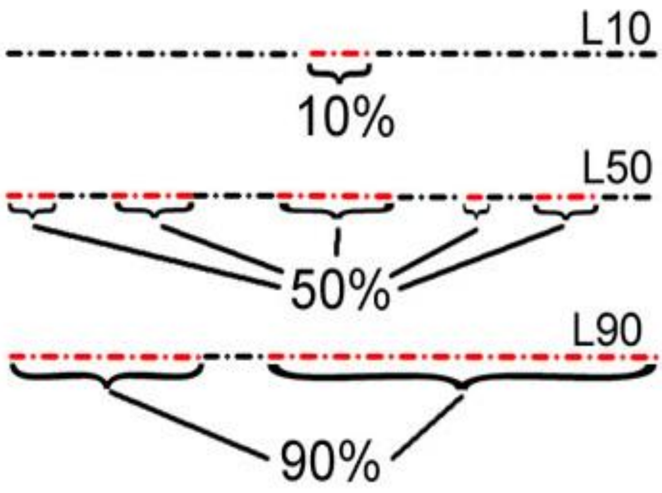


Figure 3.6 Statistical noise indicators, Ln

Source: **(Witt, 2005)**

The indicator Leq adopted internationally to be the most representative noted in one spot and for a certain period, it is expressed in dB. Equation 7 presents the calculation of Leq:

$$L_{eq} = 10 \times \log\left(\frac{1}{T}\int_0^T \left(\frac{P_t}{P_0}\right)^2 dt\right) \quad (7)$$

Where:

P_t, is the instantaneous sound pressure in Pa.
P_0, is the reference pressure ($P_{ref} = 20 \times 10^{-6}$ Pascal).
T, is the measurement time.

3.5 Noise in cities

The Global Health Observatory (GHO, 2014), has stated that more than 54% of the whole world's population now lives in cities as of 2014, and predicted that this rate going to reach 75% by 2050.

Noise has become a main feature of the cities, and overcrowding is the primarily responsible for it. Most of the urban population considered that excess noise occupies the second place immediately after the water pollution within the environmental issues that retained their interest. A study carried out by the Department of Housing and Urban Development in the United States that the urban population in most cases considered that the noise is the worst trait for residential areas. Where also identified noise and crime are the biggest factors among many that lead the people's desire to relocate to another part of the city (Preacher, 2001), therefore, noise in cities is a permanent and chronic problem.

The load of noise affects human health and as cities grow if development continues as it has done historically, it will be likely to affect greater numbers. In modern cities, the noise comes almost always from motorized transport, from roads, railroads, and aircrafts. Often the most pervasive is road noise because it propagates almost into the whole city and to every corner of it (Pope, et al., 2014).

3.5.1 Noise in Syria

The Syrian cities from several decades were considered as quite cities, except the voices of hawkers and emanating sounds from some handicrafts and little cars that cross the roads from time to time.

But this reality shift radically changes with the development of cities, and most urban areas and even rural communities become with high noise levels that often exceeded the permissible limits. Recent studies about noise carried out by the Atomic Energy Commission have shown that the average noise levels in most areas of Damascus are between 70 and 80 dB(A) and the same in the city of Aleppo, these levels appear even in residential areas were the daytime noise levels shouldn’t exceed 55 dB(A). There were high noise levels both in residential and hospitals areas which show that the noise levels were higher than the permissible limits at a rate more than 30 dB(A).

What increases the risk of significant differences in noise levels from one moment to another, that sometimes differences are up to 30 dB(A), and these differences caused by the sudden voices resulting from car and motorcycles horns, buses, trucks and other traffic sources. Noise levels also remain high even after the evening (EPC, 2002).

In Syria, the Environmental Protection Council (EPC) introduced in 2002 the legal limits of noise levels and the safe period of exposure to reduce this unwanted phenomenon. They divided the city into zones depending on its functions and the day into three periods; day, evening, and night period.

Table 1 The legal limits of noise levels in Syria
Source: (EPC, 2002).

ZONES	DAY 7:00 AM to 6:00 PM	EVENING 6:00 PM to 10:00 PM	NIGHT 10:00 PM till 7:00 AM
Commercial administrative and city center zone	55 - 65	50 - 60	45 - 55
Industrial zones	60 - 70	55 - 65	50 – 60
Rural residential areas, hospitals, and gardens	35 - 45	30 - 40	25 - 35
Residential areas in the city	45 - 55	40 - 50	35 - 45
Residential areas with some workshops business or near the highway	50 - 60	45 - 55	40 - 50
Residential neighborhoods	40 - 50	35 - 45	30 - 40

3.6 Sources of noise pollution

In general, there is two sources of noise pollution, i.e. industrial sources and non-industrial sources. The first includes the noise from different industries and various types of big machines that work at a high-speed and high-density. The non-industry source includes noise generated by transportation, and neighborhood noise, which created by nature and manmade various noise pollution (Bhatia, 2014). Figure (3.7) represents some sound levels produced by typical noise sources.

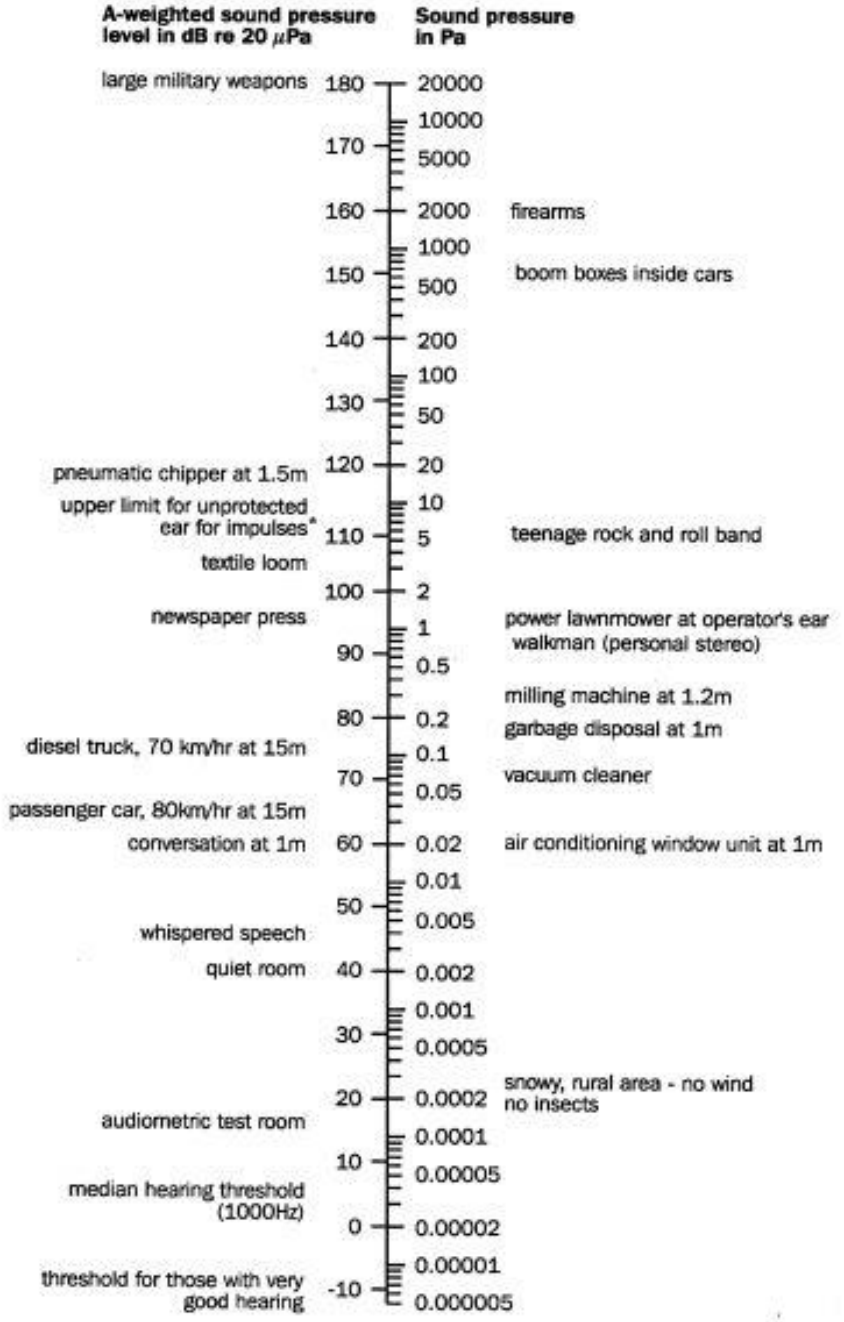


Figure 3.7 Illustration of sound levels produced by typical noise sources
Source: **(Bhatia, 2014)**

3.6.1 Sources of noise in cities

Most leading noise sources are roads traffic, aircraft, railroads, construction, industry, noise in buildings, and consumer products. The most two significant sources that should be preventable, arise from road traffic and industry. Motor vehicle traffic is often the greatest contributor of noise in most cities (CPAS, 2010).

3.6.1.1 Industrial noise

It is noise produced by various industries, it is produced at every stage in industry by deferent aspects like welding, hammering, drilling, running machinery, motors, sheet metal work, lathe machine work, operation of cranes, compressing, breaking, molding, steaming, boiling, cooling, heating, painting, transporting etc. It creates a very serious noise problem in a large scale and it has significant impacts on industrial workers as well as surrounding people.

Mechanical noise is considered as a part of industrial noise due to all kinds of machines and it increases with the type of operation and machines power capacity. The characteristics of industrial noise vary from a specific industrial process to another (Faridi, 2013).

3.6.1.2 Road traffic noise

Road traffic is the most prevalent source of noise in all countries and the most widespread cause of discomfort and interference. The statistics have proven that traffic causes 75% of the cities noise pollution. It is directly linked to the number of vehicles, which increase with the increasing of population, meaning increasing of the population leads to increasing in noise pollution.

Traffic noise not only depends on the numbers of vehicles, it also depends on some other factors; the road conditions, traffic cleaner, vehicles condition, common sense, and the speed of the vehicle. The noise output of all automobiles components (exhaust, intake, engine fan, and tires) increases with speed, for example increasing the speed of a car from 30mph to 60mph will increase the noise level about 10dB(A).

The people living near highways and transit roads are mainly exposed to this noise. For example, a heavy truck produces around twenty to thirty times more sound energy than a personal vehicle (Faridi, 2013).

3.6.2 Patterns of noise sources emission

There are many sources of noise that differ among themselves in the direction of the propagation of sound waves emitted from them, which leads in different ways to control them to reduce the noise levels, so we can classify the noise sources into three kinds:

3.6.2.1 Point sources

The point sources represented by the location of the body that send sonogram in all directions, which are propagated in a spheroid way around the location of the source if it is in the air. These directional sound waves vary depending on the location of this source from neighboring surfaces that affects the intensity values and levels of acoustic energy and the level of noise emitted from it. Figure (3.8) represents the propagation of the noise from a point source.

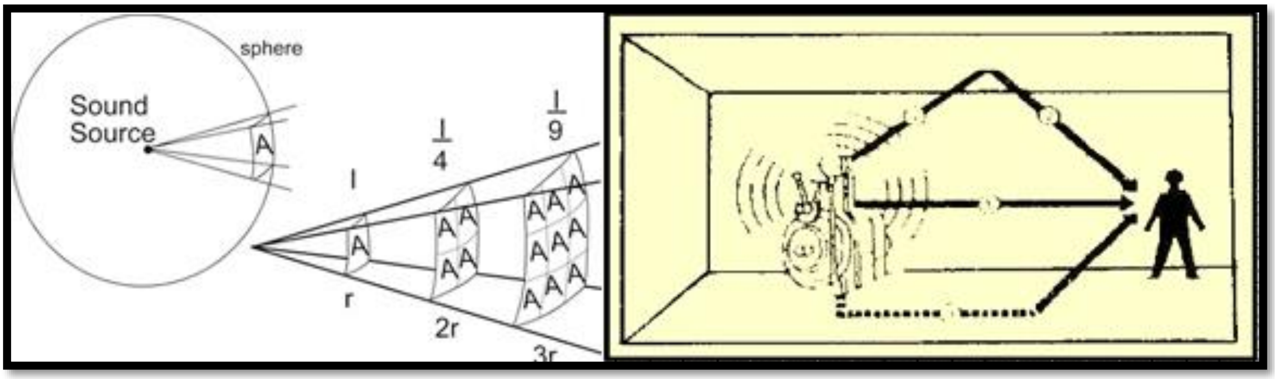


Figure 3.8 Illustration of propagation of noise from a point source

3.6.2.2 Line sources

Represents the line source of a group of bitmap sources which has a continuous movement in a straight line away from each other in a certain and equal distance, moving in different speeds and propagate sound waves in a half-cylinder shape along the line of the movement. The linear source represents a crowded path or line passing trains, and the linear source could have limited length as in cities where it is usually limited between two points, or unlimited length where the receive location outside the cities like in rapid passageways. Figure (3.9) represents the propagation of the noise from a line source.

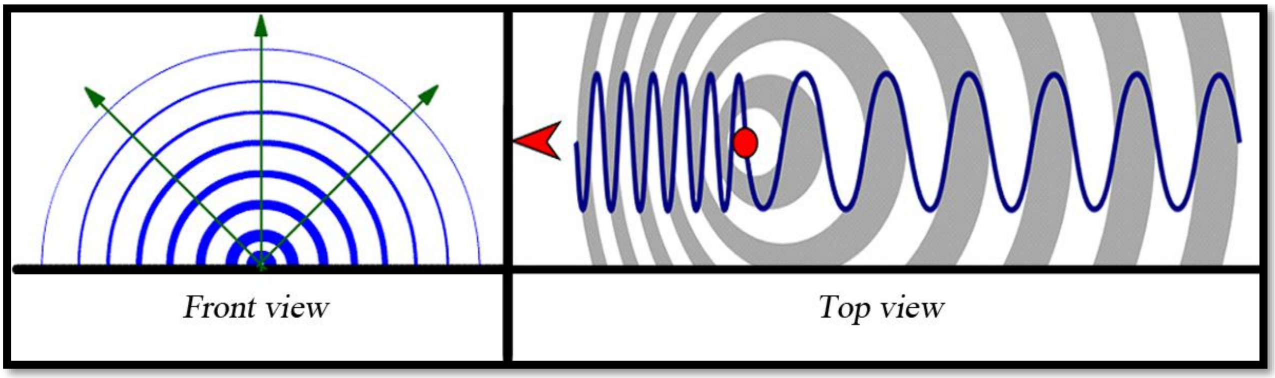


Figure 3.9 Illustration of propagate of noise from a line source

3.6.2.3 Surface sources

Represents a surface or interface for noisy building, where it propagates sound waves through a two-dimensional surface like machinery room interface, lab interface or window on the wall. The transmission of noise through this surface to neighboring areas the recipient is the person who stands at a distance from this interface and the source surface is the generator surface noise. Figure (3.10) represents the propagation of the noise from a plan source.

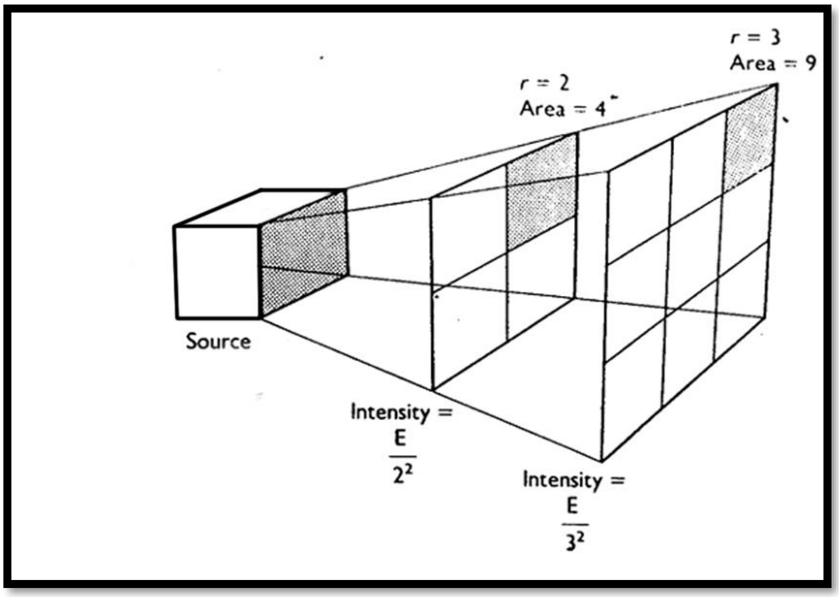


Figure 3.10 Illustration of propagation of noise from a plan source

3.7 Types of Noise

There are various types of noise, the selection of instrument and equipment to measure it is based upon its type **(Hansen, 2001)**, as follows:

Steady noise:

Is a noise with insignificantly small variation of sound pressure level during the time of observation.

Non-steady noise:

When the sound pressure changes significantly within the period of observation. This type of noise could be two types: Intermittent noise and fluctuating noise.

Fluctuating noise:

The level of noise changes continuously and to a high range during time of observation but has a long-term average (LAeq,T).

Intermittent noise:

The noise level is a background one that increases and decreases rapidly within the time of observation, which means it is a constant noise that starts and stops rapidly.

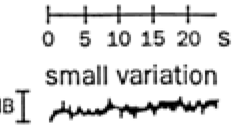
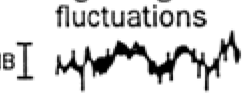
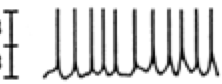
Tonal noise:

Could be continuous or fluctuating because it has one or two single frequencies.

<u>Impulsive noise:</u>

The noise level lasts for a very short period, less than one second.

Table 2 Noise types and their measurement.
Source: (Hansen, 2001)

	Characteristics	Type of Source
0 5 10 15 20 s small variation 10dB 	Constant continuous sound	Pumps, electric motors, gearboxes, conveyers
intermittent noise 10dB 10dB  background noise	Constant but intermittent sound	Air compressor, automatic machineryduring a work cycle
large fluctuations 10dB 	Periodically fluctuating sound	Mass production, surface grinding
large irregular fluctuations 10dB 	Fluctuating non-periodic sound	Manual work, grinding, welding, component assembly
similar impulses 10dB 10dB 	Repeated impulses	Automatic press, pneumatic drill, riveting
isolated impulse 10dB 10dB 	Single impulse	Hammer blow, material handling, punch press, gunshot, artillery fire

3.8 The factors affecting the propagation of sound

The propagation of noise depends on the distance between the emission source and the receiver, the noise decreases with increasing of this distance. i.e., If a point source in a free field with normal conditions produces a sound pressure level of 90 dB at a distance of 1 meter, the sound pressure level at 2 meters is 84 dB, at 4 meters is 78 dB, and so forth (U.S. Department of Labor), as seen in Figure (3.11). This reduction depends on various factors such as the type and source of the surrounding soil, the absorption characteristics, and the existence of barriers.

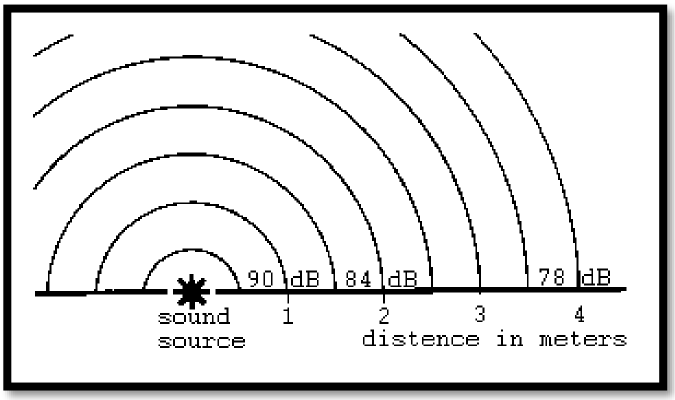


Figure 3.11 Illustration of the distance between the emission source and the receiver

The weather conditions also have a strong influence on the propagation of noise, the most important factors are wind and temperature. The sound increases when the wind direction is from the source to the receiver and decrease when the wind is in the opposite direction (Oliveira, 2011).

The temperature related with the sound velocity when the temperature is high the sound velocity will be higher. The propagation of sound velocity depends on the air density and air pressure. Therefore, the sound velocity related with the humidity, because the air density is greatly influenced by humidity.

Since the atmospheric pressure does not influence noise propagation, the air pollution, mainly carbon monoxide and carbon dioxide are highly absorbent, greatly attenuating the sound propagation (Fernandes, 2002).

3.8.1 Planning factors

<u>Wind direction:</u>

As previously explained, the sound increases when the wind direction is from the source to the receiver and decrease when the wind is in the opposite direction. When the wind is moving from the listener to the noise source, this makes the sound waves bend upward away from the earth's surface (see Figure (3.12-a)), and this creates an area under the voice (noise-free zone). However, when the wind direction is in the same direction as the noise it makes sound waves bend down in the direction of the earth's surface (see Figure (3.12-b)) destined fully towards the listener (CPAS, 2010).

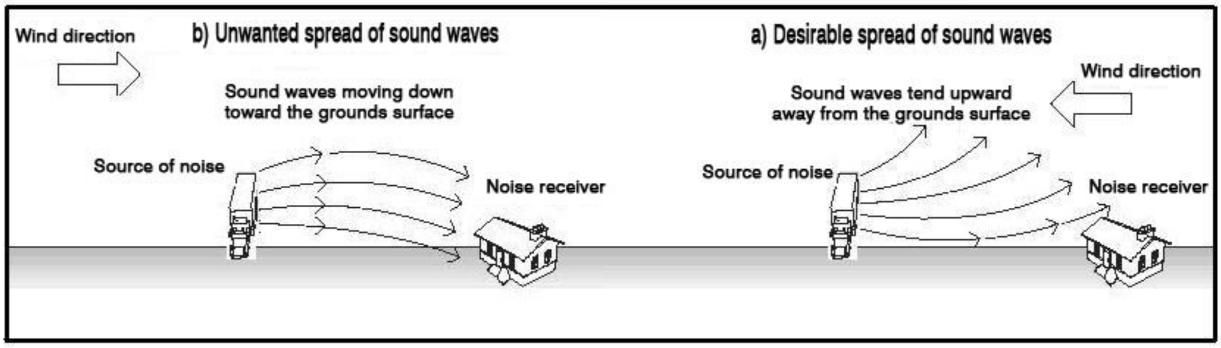


Figure 3.12 Illustration of the effect of wind direction on the spread of sound waves
Source: (CPAS, 2010)

The topography of the site

In the case of a tendency in the site ground we should put the roads in high tendency level and distribute the buildings in the low tendency level in the noise shadows zone so the noise impact significantly decreases on the building facades without using barriers see Figure (3.13 - a). While in the case of difficult tendencies, we can put the roads in the low tendency level and distribute the blocks on the hills in the shade noise zone formed by the site tendencies as shown in Figure (3.13-b), (CPAS, 2010).

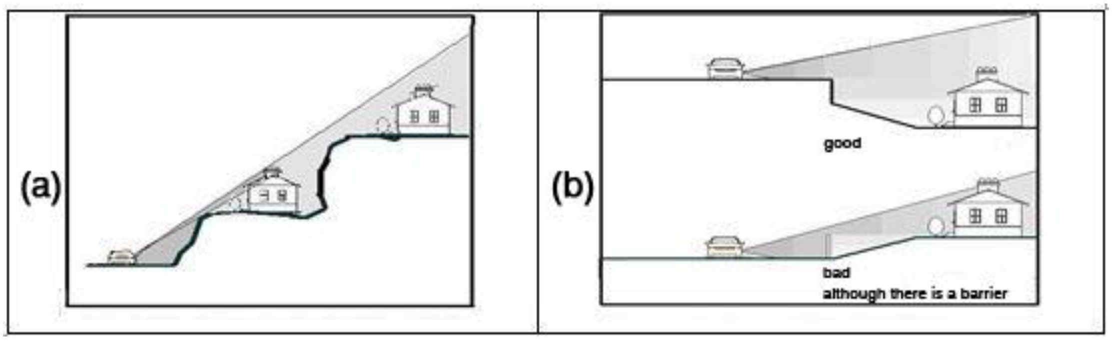


Figure 3.13 Illustration of exploit the site topography to reduce road noise
Source: (CPAS, 2010)

Roads lined with high buildings (canyon)

The lines of high buildings on both sides of the road hold the noise in what looks like a canyon. Whereupon the facades of buildings, the frequency reverse the sound waves, which cause an increase in noise level. The impact of this overload noise is similar to the impact of the audio feedback phenomenon. Thus, the severity of this phenomenon increases directly proportional to the vacuum containment ratio increase, in other words, it increases directly proportional to increase the ratio between the width and the height of the building (CPAS, 2010).

3.8.2 Design factors

The building formation and orientation

Figure (3.14-a), shows one example of forming the building shape in order to create an outer space protected from noise using the building properties, and this principle can be applied to a lot of shapes. Using the buildings mass to create quiet outer spaces is more efficient than using other obstacles to achieve the same purpose (CPAS, 2010).

The distribution of the building components

It is possible to reduce noise exposure, by putting noise sensible buildings components (such as bedrooms) in the back, and putting less noise sensible components (such as kitchen and bathrooms) between them and the road.

In the inevitable case of putting a noise sensible component in the front of the building (Facing the road), it is better to do the openings (windows and terraces) on the perpendicular facade to the road in order to reduce noise. See Figure (3.14-b) (CPAS, 2010).

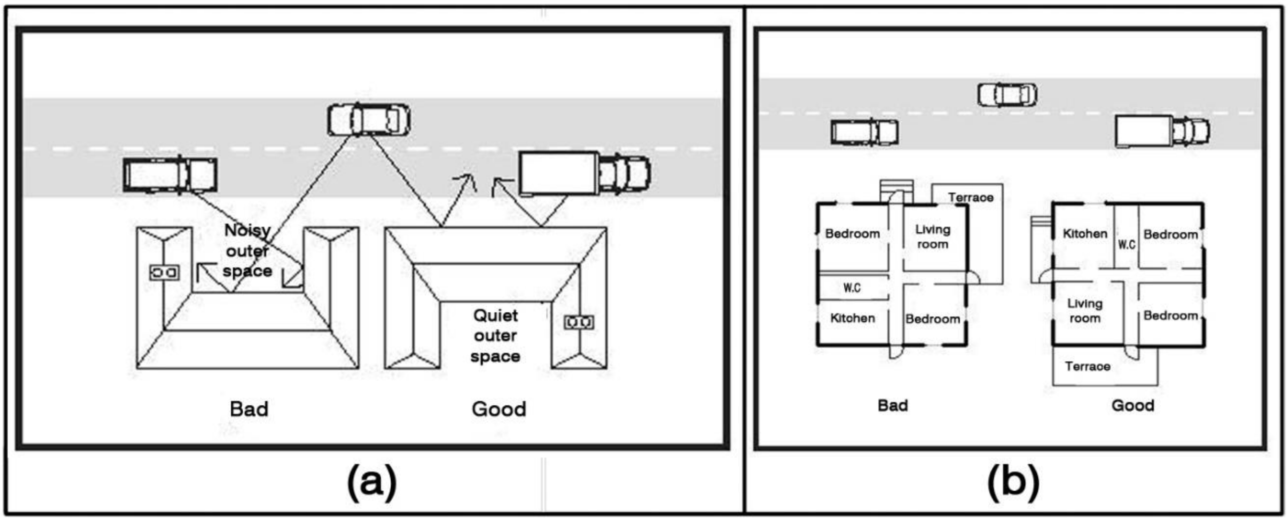


Figure 3.14 Illustration of design factors
Source: (CPAS, 2010)

3.9 The harmful effects of noise

According to (Institute, 2010) there is no precise way to specify the type of relationship between noise and its resulting effects, because those effects vary from one person to another depending on several factors, including:

1. Noise intensity and level, the impact and the severity of the risk increases with the duration of exposure.
2. The acute of noise, sharp sounds are considered more impressive than the large sounds.
3. The distance from noise source, closer distance increases the influence of the sounds.
4. The unpredictability of sound, the unpredictable sound has more influence than the continued noise on human being.

3.9.1 Auditory disorders

The effect of sound waves with a certain magnitude on the ear would present damages to the human auditory. When a human being is exposed to a sound with an intensity of (70 dB) it starts to cause him disturbance, and when the intensity of the sound is increased to (90 dB) and more it starts to affect the body organs, if the noise continues for a long time it causes intensive damages in the inner ear nerve cell, which gradually erodes those cells to eventually causes deafness, this kind of deafness known as nervous deafness. In this regard, recent studies conducted on factory workers have proven that out of five workers there is one with a deaf injury.

The other type of deafness called auditory deafness, causes ruptured eardrum in the case of sudden intense noise such as explosions (higher than 140 dB), and this kind of noise may cause a heart attack for people with heart problems. (Al-Baaz, 1998).

3.9.2 Physiological effects

Sometimes noise has several serious damages, street noise in cities affects the circulatory system, it causes disturbances in the heart functions and an increase in blood pressure, also it creates nervous system disorders. As well as long exposure of stress-acoustic raise the pressure of cerebrum fluid and spinal cord. (Meselhi, 2008). It also causes interception in the stomach cramps and lack of stomach secretions, as the auditory stimuli affects the glucose curves, diabetics are more sensitive to noise, therefore, there are a lot of diseases associated with noise. (Bacaks, 1985).

3.9.3 Psychological effects

The continuous and the high volume voices (higher than tolerable) lead to a decrease of vital activity, anxiety, internal uneasiness, confusion and lack of harmony. Exposure to noise for a period of one second reduces the concentration for 30 seconds. (Abd Al-Razek, 1988).

3.9.4 Impact on human productivity

Noise has serious effects on people who have mental and intellectual works, where perceptible differences in the production are found between the work performed in a calm atmosphere, and the work performed in an atmosphere saturated with noise. It is well established that noise caused about 50% of errors in mechanistic studies, and about 20% of occupational accidents, all of this leads to a reduction in the productive capacity of the individual and a negative impact on economic terms. It is obvious that weak and declining production necessarily affect the national economy of the state, so this entity must take into consideration creating a healthy environment free from pollution, in the workplace to achieve the desired goal of work and production.

3.10 Environmental noise measurement

3.10.1 Noise measurement equipment

For carrying out measurement of environmental noise there are several types of measurement systems and many equipments, depending on the aim of the measurement, the sound characteristics and the range of information that is wanted about the sound (Malchaire, 2001).

We can distinguish the acoustic measurement equipment from devices that measure the sound pressure levels and devices that measure sound intensities.

3.10.2 Sound pressure levels measuring equipment

Sound level meter (SLM)

The sound level meter (SLM) is a device that measures the sound pressure level to determine it. The most commonly weighting used by (SLM) is the A-frequency-weighting filter to simulate the subjective response of the human ear, but B-, C-, D-, and Z-frequency-weightings also exist.

The (SLM) consists of a **microphone** that let the sound enters to the device as an electrical signal, **electronic circuitry** to work on this signal so it can measure the desired characteristic, and a **readout display** so the measurement in decibel can be displayed (Britannica, 2013).

Figure 3.15 Sound level meter (SLM)

Noise Dosimeter

The noise dosimeter or noise average meter is a specialized sound level meter designed specifically to measure the noise levels. It stores the information of noise levels and carries out the average values. It measures the air pressure that fluctuate by sound and transform it into a usable reading.

3.10.3 Sound intensities measuring equipment

Octave band analyzer

Octave band analyzer defines the suitability of different types of frequency depending on noise control. The octave band measurement is used to define the frequency composition of a sound field. In addition, it can be used to analyze the alternating current (AC) analog output of the (SLM).

Since the audible frequencies for human range from 20-20000 Hertz (Hz), the octave band divides the frequency from 20 to 15000 Hz into 8 frequencies range, as seen in Table (3) (Philipp, 2010).

Table 3 Frequency range and average value
Source: (Philipp, 2010)

Number	Frequency range	Average value
1	20- 90 Hz	63 Hz
2	90- 179 Hz	125 Hz
3	179- 352 Hz	250 Hz
4	352- 704 Hz	500 Hz
5	704- 1.408 Hz	1000 Hz
6	1.408- 2.816 Hz	2000 Hz
7	2.816- 5.600 Hz	4000 Hz
8	5.600- 15.000 Hz	8000 Hz

Statistic noise analyzer (SNA)

The statistical noise analyzer was designed to analyze frequency that is largely produced by lightning discharger as highly impulsive atmospheric electromagnetic noise, which is very low frequency (VLF), and low frequency (LF) (SATPAL, 2012).

3.11 Environmental noise prediction methods

From a technical point of view, the methods of prediction are the best to determine noise levels that are caused by road traffic on an ongoing basis. In addition, it becomes possible to know various scenarios with different elements such as different traffic flows, various types of flooring, etc. (Oliveira, 2011).

Theoretically, noise will be estimated under a set of conditions, these needs to be fixed in any physical environment or “snapshot”. However, practically the environment is usually not stable or fixed and normally the conditions will be constantly varying. These variations in environmental conditions cause the sound level to be different also according to time and space. Therefore, it is important to know that the information that we are going to obtain from the prediction of noise will be representing an estimation of a snapshot from the range of the actual environmental noise levels that happened in specific time and space (OECD, 1995)

To obtain close to reality results of the actual sound levels, there is a need to have a specific set of conditions that are related to. Firstly, noise sources and secondly physical environment, which the noise will travel from the source to the receiver location or the area of interest, which include the ground cover, the surroundings environment and the atmospheric factors (e.g. wind, temperature, humidity). Lastly, how the sound will be reduced through his transition from the source to the receiver due to air, soil and other obstacles (HLA, 2010).

Thus, to predict an environmental noise there is a need to define and investigate a series of noise sources, so we can define the acoustic substantial features of the environment through which sound will propagate to the receiver, then producing an estimated noise level at the area of interest by applying some calculation methods (HLA, 2010).

The Road Noise Prediction Method is broken down into two models:

- The first one is used to relate the power of sound with road traffic in an infrastructure, and it is called 'Calculation of sound emissions from road traffic' (Abaques, 2008)
- The second one is used to calculate noise level from an infrastructure represented by its sound emissions in a long-range, and it is called 'NMPB 2008 – noise propagation method included meteorological effects'. This model will be used in this study.

3.11.1 Noise prediction model (NMPB 2008)

The new version of the noise prediction method 'NMPB 2008' is the update of the 'NMPB96' version, which was adopted to be used under Directive 2002/49/EC as a reference method in order to be a harmonized European method in the assessment and management of environmental noise (Setra, 2009).

This model presents a calculation method dealing with the outdoor road noise propagation and take the meteorological conditions effects into account, it can be used under French regulations requirements.

The NMPB 2008 follows two types of the principle of detailed calculation of long-range sound levels, which are types of meteorological conditions; downward-refraction conditions, and homogeneous conditions. The result is conceived by an accumulation of energy in sound levels that are noted in these conditions, weighted according to the possibility of occurrence of downward-refraction conditions in the study location. Thus creating an atmospheric condition profile for a long time, by taking into question the upward-refraction conditions of propagation (where the lowest noise level is received) with homogenous, conditions which protect the inhabitants better (Setra, 2009).

3.12 SOFTWARE

To study the effect of noise generated by sources of noise from urban form on the facades of buildings, it is necessary to use software that reads urban forms, sound pressure and frequencies and link them to each other. Software which gives numeric results, and graphs, it helps to understand this effect and help to create scenarios of urban forms with the least noise. One of the most used software in this area is CadnaA.

3.12.1 CadnaA

CadnaA (Computer-Aided Noise Abatement) is a software to calculate, display, assessment and prediction of environmental noise. Whether to study the noise of industrial facilities, urban areas or even entire towns, and what they include from passages, parking, roads, railways, etc. CadnaA has been designed to deal with all these tasks.

CadnaA is easy software to use and is the best software to deal with national and international noise calculation and noise mapping projects of any size.

CadnaA offers a lot of ways and strategies to present the results for any kind of purpose, such as: Result table, Object labelling, Horizontal noise maps, Building noise maps, and Histograms (DataKustik, 2014).

3.12.1.1 Modelling and calculation

CadnaA offers numerous tools to set up your calculation model, to present the results and to communicate with related applications like spreadsheet programs, CAD software or GIS systems via import and export interfaces. All of these tools are designed to be as easy to use as possible.

The calculation of noise levels is always done accurately to the latest international standards and guidelines. Due to the implemented powerful acceleration techniques and refined algorithms, CadnaA is by far the fastest noise prediction software on the market (DataKustik, 2014).

3.12.1.2 Calculation of noise levels

CadnaA calculates the noise levels at any location, whether in a form of point arranged on a horizontal or vertical grid, or even on grids enveloping all building facades. We can select many national and international criteria for this sound calculation. For some special sources like roads, railways and airports the acoustic emissions quantities are calculated from the technical parameter values (DataKustik, 2014).

CHAPTER 4

4 CASE STUDY

In order to address the environmental noise problems in the urban spaces in terms of the relation between the urban noise and the urban forms, this study is going to present eight different Syrian urban forms, referred and adjusted to the same reference area, and calculate the physical characteristics of each one depending on their dimensions using AutoCAD software. Then it will apply on them five different urban indicators, which can be applied to other patterns of various forms and can help in constitute a fundamental rule making the comparison between urban forms easier.

Afterwards, for carrying out measurement of environmental noise and noise levels on the buildings facades, assuming the roads are the noise sources, the study is going to adopt the noise prediction method 'NMPB96' as a base, and it will apply certain noise indicators that are generally used to characterize the external acoustic environment, using the CadnaA software.

4.1 Urban Forms Methodologies

The urban forms used in this study are eight real Syrian forms, of medium multifamily buildings with four floors height. The chosen urban forms have various ways of implementation as represented in Chapter 2; closed implementation, linear implementation and punctuate implementation, Figure (4.1).

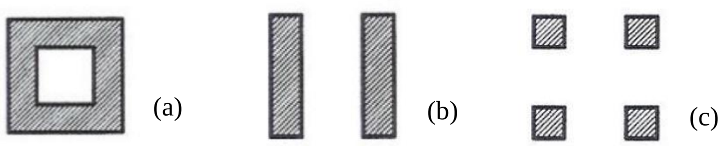


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Figure 4.1 Illustration of: closed (a), linear (b), and puncture (c) implementation

Each form has been referred and adjusted to the same reference area, has been repeated to fit it, and was given a numerical designation in order to make the comparison between the forms possible and easier to read from the theoretical point of view. Thus, we can employ all forms in the study proposed by the following presented figures.

The reference area is determined by 300.20 m × 106.50 m, in the total area of 31971.30 m², and a perimeter of 813.4 m linear.

The used streets in the reference area are local streets with various local access routes, each street is two ways rout with a width of 5 m, 2.5 m for each way. There are various forms of used local road accesses as mentioned in Chapter two; Continues access, ring access, square access and dead-lock access, as shown in Figure (4.2).

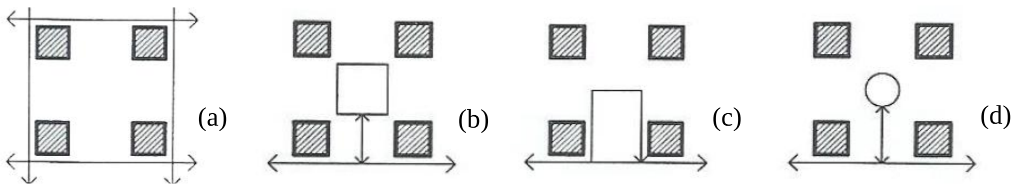


Figure 4.2 Illustration of: continues (a), square (b), ring (c), and dead-lock (d) access.

Urban Form N°1:

The implementation of the buildings depending on the main streets is a mixed implementation (aligned and unaligned implementation). The local streets are continues, and the road accesses to this form are dead-lock accesses. It was possible to replicate the first form two times in the reference area, as illustrated in Figure (4.3).

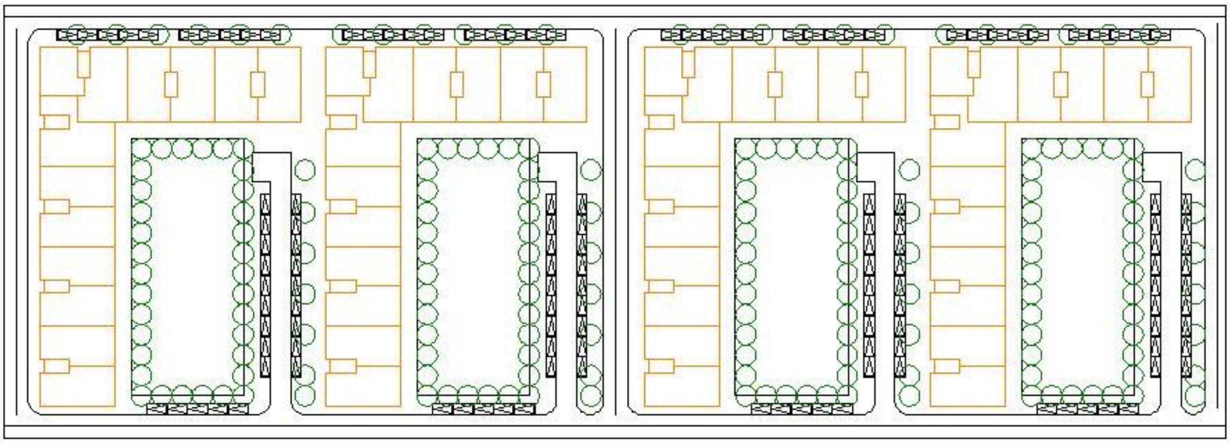


Figure 4.3 Illustration of urban form 1

Table 4 Physical characteristics of urban form 1

	Urban Form 1
Patch area (m²)	2430.7
N°.Patch (m)	4
Perimeter Patch (m)	314.0
Implantation area (m²)	9722.8
Surrounding radius (m)	44.7
Reference area (m²)	31971.3

Urban Form N°2:

The local streets are continues, and the road accesses to this form are dead-lock accesses. The implementation of the buildings depending on the main streets is a mixed implementation (aligned and unaligned implementation). It was possible to replicate the second form two times in the reference area, as illustrated in Figure (4.4).

Table 5 Physical characteristics of urban form 2

	Urban Form 2		
Patch area (m²)	1652.5	951.6	1171.2
N°.Patch (m)	2	4	4
Perimeter Patch (m)	217.2	140.6	164.6
Implantation area (m²)	11796.2		
Surrounding radius (m)	45.2	32	26
Reference area (m²)	31971.3		

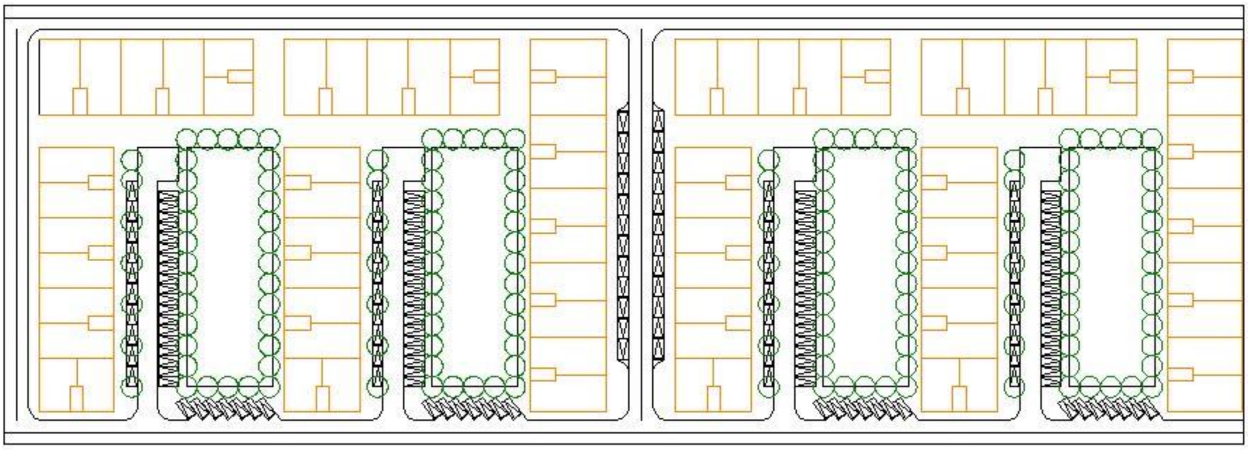


Figure 4.4 Illustration of urban form 2

Urban Form N°3:

The implementation of the buildings in the third form is puncture implementation, and it is aligned to the main streets. The local streets are continues, and the accesses are continues as well. In the reference area, it was possible to replicate the third form two times as a full form and the third time was partly replicated (see Figure (4.5)), but all the values were taking into account in the calculation, as illustrated in Table (6).

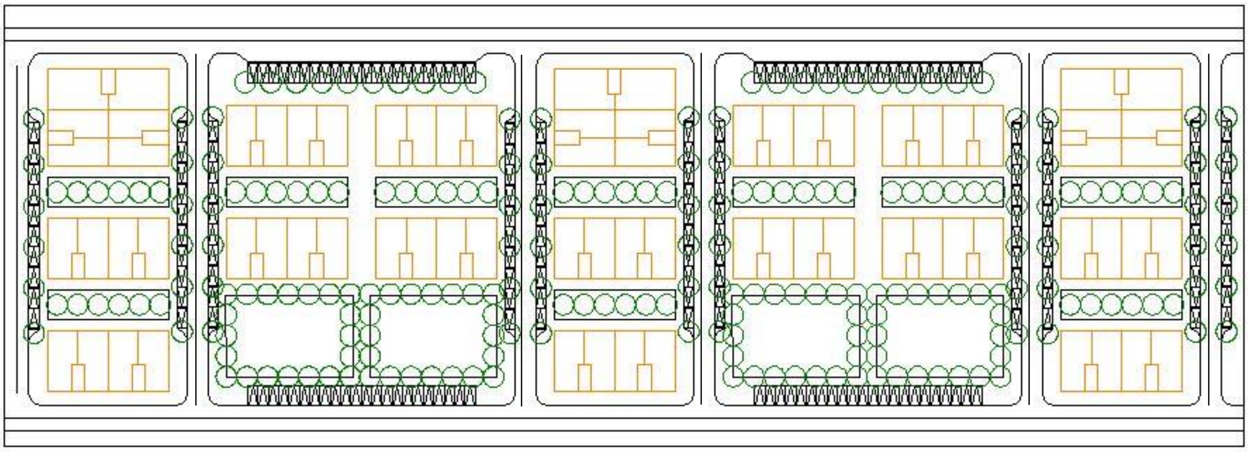


Figure 4.5 Illustration of urban form 3

Table 6 Physical characteristics of urban form 3

	Urban Form 3	
Patch area (m²)	689.1	426.3
N°.Patch (m)	3	14
Perimeter Patch (m)	105.6	87.6
Implantation area (m²)	8035.8	
Surrounding radius (m)	14.6	14.6
Reference area (m²)	31971.3	

Urban Form N°4:

The implementation of the buildings in the fourth form is puncture implementation, and the implementation of the buildings depending on the main streets is mixed implementation (aligned and unaligned implementation). The local streets are continues, and the road accesses to this form are ring accesses. In the reference area, it was possible to replicate the fourth form two times as a full form and the third time was partly replicated (see Figure (4.6)), but all the values were taking into account in the calculation, as illustrated in Table (7).

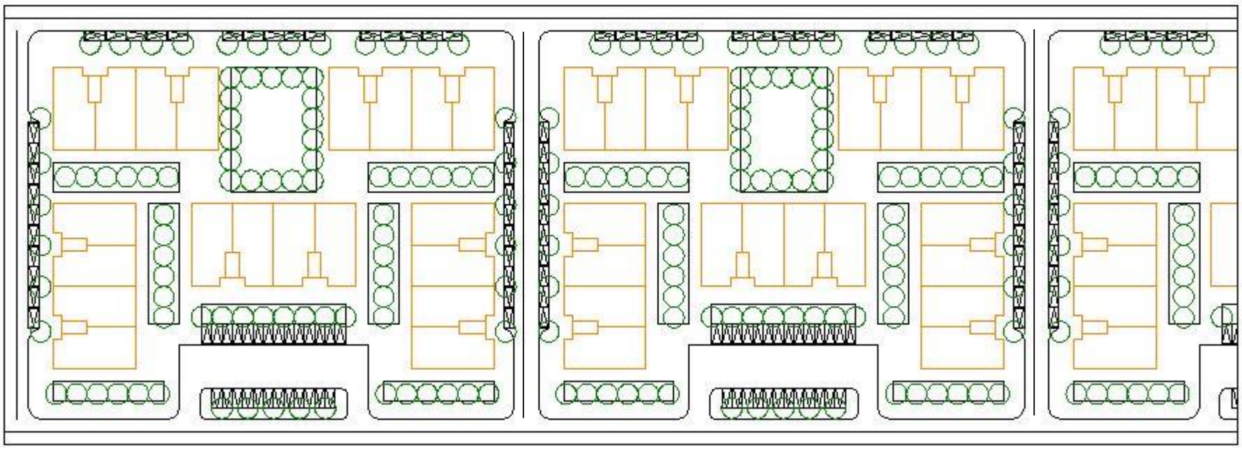


Figure 4.6 Illustration of urban form 4

Table 7 Physical characteristics of urban form 4

	Urban Form 4
Patch area (m²)	776.0
N°.Patch (m)	12
Perimeter Patch (m)	128.0
Implantation area (m²)	9312.0
Surrounding radius (m)	20.0
Reference area (m²)	31971.3

Urban Form N°5:

The implementation of buildings in the fifth form is puncture implementation, and it is unaligned to the main streets. The local streets are continues, and the accesses are continues accesses as well. In the reference area, it was possible to replicate the fifth form two times as a full form and the third time was partly replicated (see Figure (4.7)), but all the values were taking into account in the calculation, as illustrated in Table (8).

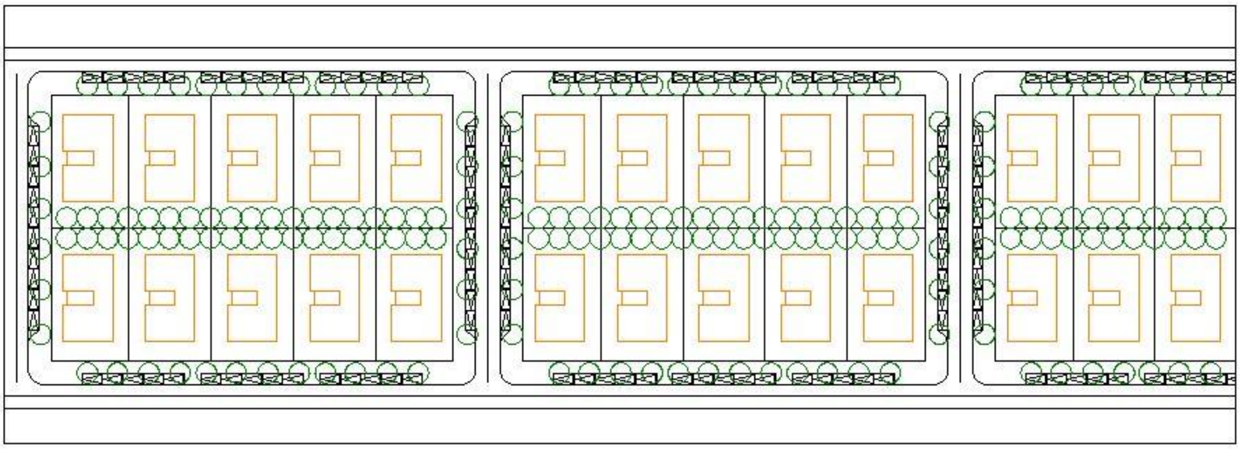


Figure 4.7 Illustration of urban form 5

Table 8 Physical characteristics of urban form 5

	Urban Form 5
Patch area (m²)	248.0
N°.Patch (m)	26
Perimeter Patch (m)	68
Implantation area (m²)	6448.0
Surrounding radius (m)	10.5
Reference area (m²)	31971.3

Urban Form N°6:

The implementation of the buildings in the sixth form is linear implementation, and it is aligned to the main streets. The local streets are continues, and the accesses are square accesses, as illustrated in Figure (4.8). It was possible to replicate the sixth form two times in the reference area.

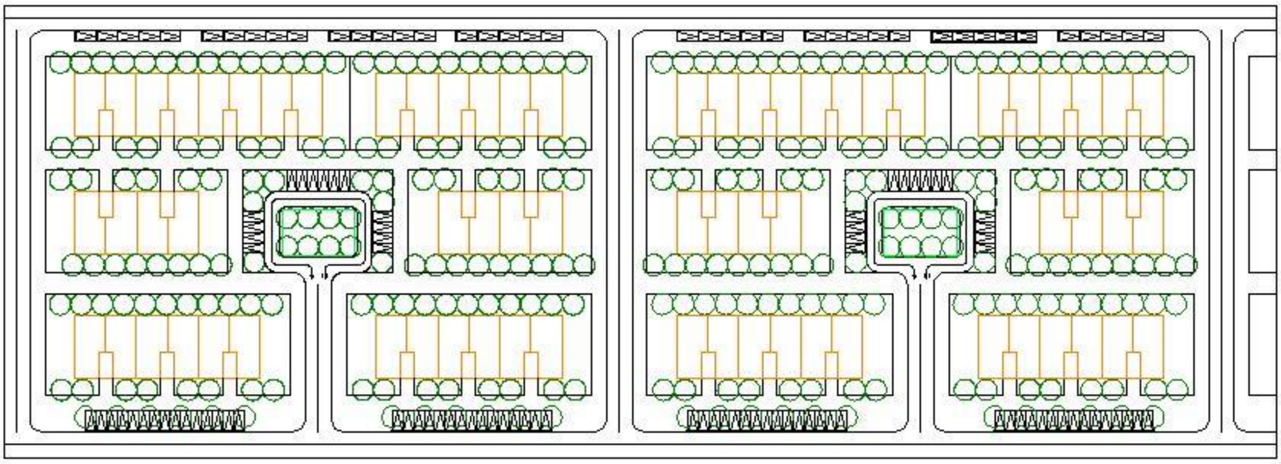


Figure 4.8 Illustration of urban form 6

Table 9 Physical characteristics of urban form 6

	Urban Form 6		
Patch area (m²)	864.3	648.2	432.2
N°.Patch (m)	2	6	4
Perimeter Patch (m)	146.4	117.2	88.0
Implantation area (m²)	7346.7		
Surrounding radius (m)	30.1	23.1	16.4
Reference area (m²)	31971.3		

<u>Urban Form N°7:</u>

The implementation of the buildings in the seventh form is closed implementation, but it contains lateral openings allowing the road accesses to enter the urban form fabric, and the implementation of the buildings depending on the main streets is mixed implementation as shown in Figure (4.9). In the reference area, it was possible to replicate the seventh form two times as a full form and the third time was partly replicated, but all the values were taking into account in the calculation, as illustrated in Table (10).

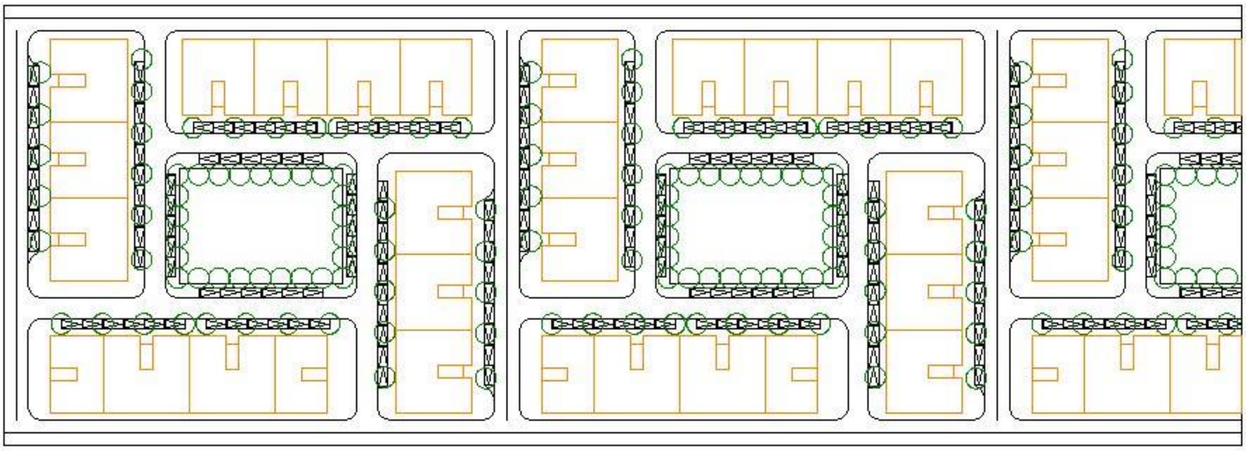


Figure 4.9 Illustration of urban form 7

Table 10 Physical characteristics of urban form 7

	Urban Form 7				
Patch area (m²)	1269.4	1063.1	1226.7	344.2	929.8
N°.Patch (m)	2	5	2	1	1
Perimeter Patch (m)	193.0	166.0	179.0	78.9	146.9
Implantation area (m²)	11581.4				
Surrounding radius (m)	35.0	29.3	33.5	9.5	25.5
Reference area (m²)	31971.3				

Urban Form N°8:

The implementation of buildings in the eighth form is linear implementation, the local streets are continues, and the road accesses to this form are dead-lock accesses. In the reference area, it was possible to partly replicate the eighth form, as shown in Figure (4.10), but all the values were taking into account in the calculation, as illustrated in Table (11).

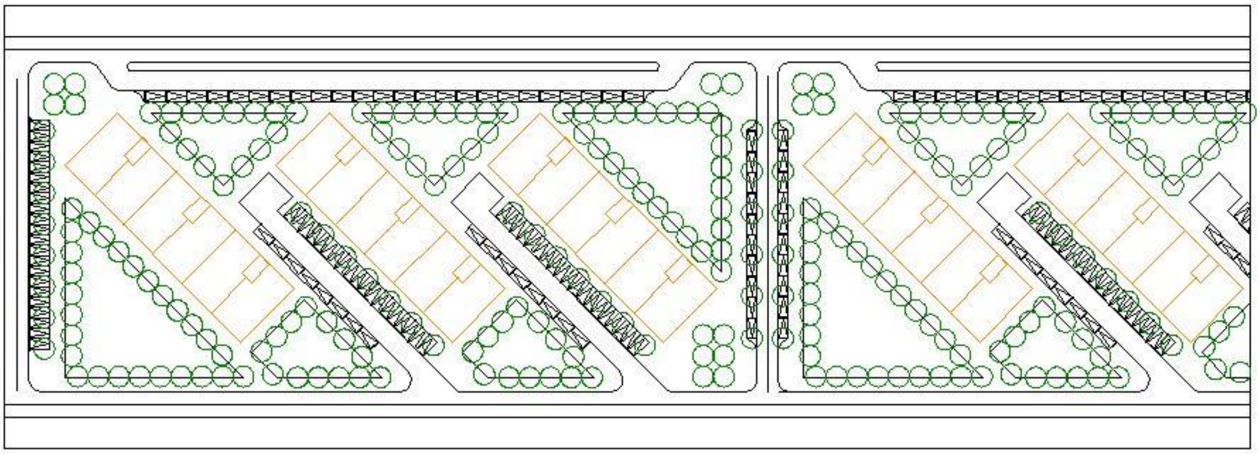


Figure 4.10 Illustration of urban form 8

Table 11 Physical characteristics of urban form 8

	Urban Form 8
Patch area (m²)	1080.0
N°.Patch (m)	5
Perimeter Patch (m)	156.0
Implantation area (m²)	5400.0
Surrounding radius (m)	30.0
Reference area (m²)	31971.3

4.2 Calculation of urban forms indicators

The used indicators have nature dimensions based on the studies that mentioned in Chapter 2, they are urban indexes and spatial metrics. Where the urban index are; occupation index (P %) and volumetric index (IV), and the spatial matrices are; porosity index (ROS), compactness index (CI) and form index (Form). These indicators can be applied to other patterns of various urban forms and can help in constitute a fundamental rule making the comparison between urban forms easier.

Table (12) below shows the result of the urban form indicators calculation:

Table 12 Urban form indicators calculation results

Forms	P (%)	IV (m^3)$\times 10^{-3}$	CI (-)	ROS (%)	Form (-)
1	30.4	136119.8	0.56	69.6	3.51
2	36.9	165146.5	0.73	63.1	2.81
3	25.1	112501.8	0.86	74.9	1.63
4	29.1	130368.0	0.77	70.9	1.65
5	20.2	90272.0	0.82	79.8	1.66
6	23.0	102854.1	0.77	77.0	2.10
7	36.2	162139.5	0.72	63.8	2.46
8	16.9	75600.0	0.75	83.1	2.26

As shown in Table (12), the second urban form has the highest **Occupation Index (P %)** value, because, as represented in Chapter 2; the occupation index identifies the surface of urban sprawl through the percentage of the implantation area of the total studied area. Moreover, from Table (5) it can be seen that the implantation area of the second form is the biggest within these eight forms, where it is (11796.18m²), and from the implementation area in Table (11) it can be seen why the eighth urban form has the lowest **P%**.

Since the study assumed that, all the buildings have the same number of floors and the same floor height (3.5m), and since the **Volumetric Index (IV)** represent the volum occupation of the studied area as represented in Chapter 2, it is understood that there is a proportional relationship between the occupation index and the volumetric index. As shown in Table (12) the second urban form has the highest **(IV)** value and the eighth urban form has the lowest one.

The **Porosity Index (ROS),** which present the ratio of the open space of an urban area by comparing it to the total studied urban area, as represented in Chapter 2. In this study, the open space is the non-built area. Thus, it is clear that the porosity index is inversely proportional to the occupation index, and that’s why the eighth urban form has the highest **(ROS)** value, and the second urban form has the lowest, as shown in Table (12).

Since the area with more regular patches and a bigger number of patches presents the highest **Compactness index (CI)** value, as represented in Chapter 2. The first urban form has irregular shape of patches and that is why it presents the lowest (CI) value, as shown in Table (12). All the other forms are regular and linear forms, so it is hard to do a comparison between them in terms of regularity, but it might be possible to be done according to the number of patches. Table (6) and Table (8), show that the third and the fifth urban forms have the biggest number of patches and they present the highest (CI) value, see Table (12).

The **Form Index (Form)** is an index that characterizes the complication of an urban area perimeter through the relationship between the perimeter and the area, so in this study the form index studies the extension or length of forms, the longer the form is the higher the form index value will be. As it can be seen in the urban forms above, it is clear that the first urban form has the longer forms, and that is why it has the highest (FORM) value, and the fifth urban form has the shorter forms and it has the lowest value, as shown in Table (12).

4.3 Noise Methodology

To study the environmental noise from the urban environment, by the assessment of noise levels on buildings facades that is produced by road traffic, the study adopted the noise prediction method 'NMPB96' as a base. This method was recommended to be used under the European Directive 2002/49/EC as a reference method in order to be a harmonized European method in the assessment and management of environmental noise (Setra, 2009).

The noise prediction method should provide reliable results, and to obtain these results there is a need to have a specific set of information that are related to: Firstly, noise sources, which in this study are the road traffic. Secondly, physical environment, where the noise will propagate from the source to the receiver location, which includes the ground cover, the geometrical divergence, the surroundings environment and the meteorological conditions (e.g. wind, temperature, humidity). Lastly, how the sound will be reduced through its transition from the source to the receiver due to air, soil and other obstacles (HLA, 2010).

For the calculation of the noise levels on the buildings facades of the chosen forms, the study used the CadnaA computer software with the calculation method 'NMPB96'. Where the road traffic represents the sources, and the receivers located along all the buildings facades with the total height of 14 m. To calculate these noise levels on the buildings facades, a square grid calculation was created around each building, with the dimension of 1.5×1.5m, and it starts receiving sound at a distance of 0.5m from the facades, as shown in Figure (4.11).

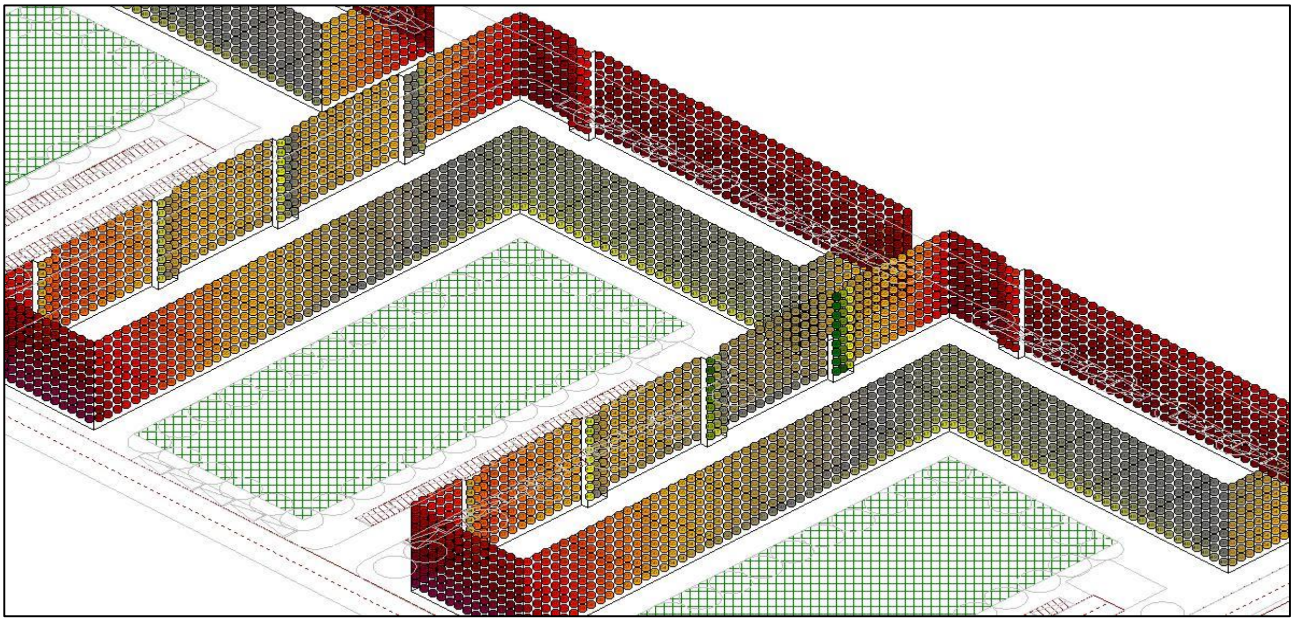


Figure 4.11 Illustration of the square calculation grid of the first form

For carrying out measurement of environmental noise, some noise indicators that are generally used to characterize the outdoor acoustic environment were used. They are: the equivalent continuous sound level, which is the average indicator (Leq), the maximum sound level, which is the maximum indicator (Lmax), and the minimum sound level, which is the minimum indicator (Lmin). The used unit for the sound level measurement was the Decibel (dB), and the used indicators were set to the A-weighting frequency scale, which is globally used for the measurements of environmental and industrial noise (Leq dB(A), Lmax dB (A) and Lmin dB(A)).

The roads referred to the same conditions in order to calculate and simulate the noise on the buildings facades, and to make the result values comparable. Three scenarios for the road traffic number and three for the vehicles speed were created, as following:

- Roads:
  - Main road traffic number: the study has 3 scenarios:
    - 200 vehicles/h, 5% are heavy vehicles for day and evening period and 0% for the night period.
    - 300 vehicles/h, 5% are heavy vehicles for day and evening period and 0% for the night period.
    - 400 vehicles/h, 5% are heavy vehicles for day and evening period and 0% for the night period.
  - Local road traffic number: 0 vehicles/h.
  - Vehicles speed: the study has 3 scenarios for each road traffic number:
    - 40 km/h.
    - 50km/h.
    - 60km/h.
  - Road surface: Smooth asphalt.
  - Road gradient: 0%.
  - Road traffic flow: Continues fluid.

4.4 Noise Calculation

Noise levels of buildings facades

The noise levels of the buildings facades for each selected form were calculated 9 times for 9 scenarios, for each node in the created calculation grid. The average arithmetic of noise levels was determined for the eight urban form and for each road conditions scenarios. Table (13), presents one of the scenarios that is the most frequented scenario (300 vehicles/h, 50km/h) where the resultant values are summarized.

Table 13 Noise level results of the scenario (300 vehicles/h, 50km/h)

Forms	Leq dB(A)	Lmax dB(A)	Lmin dB(A)	N° of calculated nodes
1	55.5	67.3	32.4	4360
2	53.5	67.2	31.8	5620
3	51.2	66.1	33.3	5310
4	51.7	63.2	32.2	5710
5	53.4	62.7	33.4	5720
6	50.0	62.2	33.1	4340
7	51.4	67.3	32.6	6305
8	56.8	61.1	46.9	2600

Noise levels within urban fabric

For the calculation of the noise levels in the urban area of the chosen urban forms, horizontal and vertical noise maps were created. To display the horizontal maps, the receivers were located along all the site area, where a square horizontal calculation grid with the dimension of 1×1m was created for each urban form to calculate the noise levels. And to display the vertical maps we created for each urban form two squares vertical calculation grids, with the dimension of 1×1m, and the receivers were located on these grids. The first square vertical grid extends as long as the reference area length and the second extends as long as the reference area width, and they both intersect midway, as seen in Figure (4.12).

The noise levels for the noise maps were presented by colors as seen in Figure (4.12), where each color represents a specific level of noise.

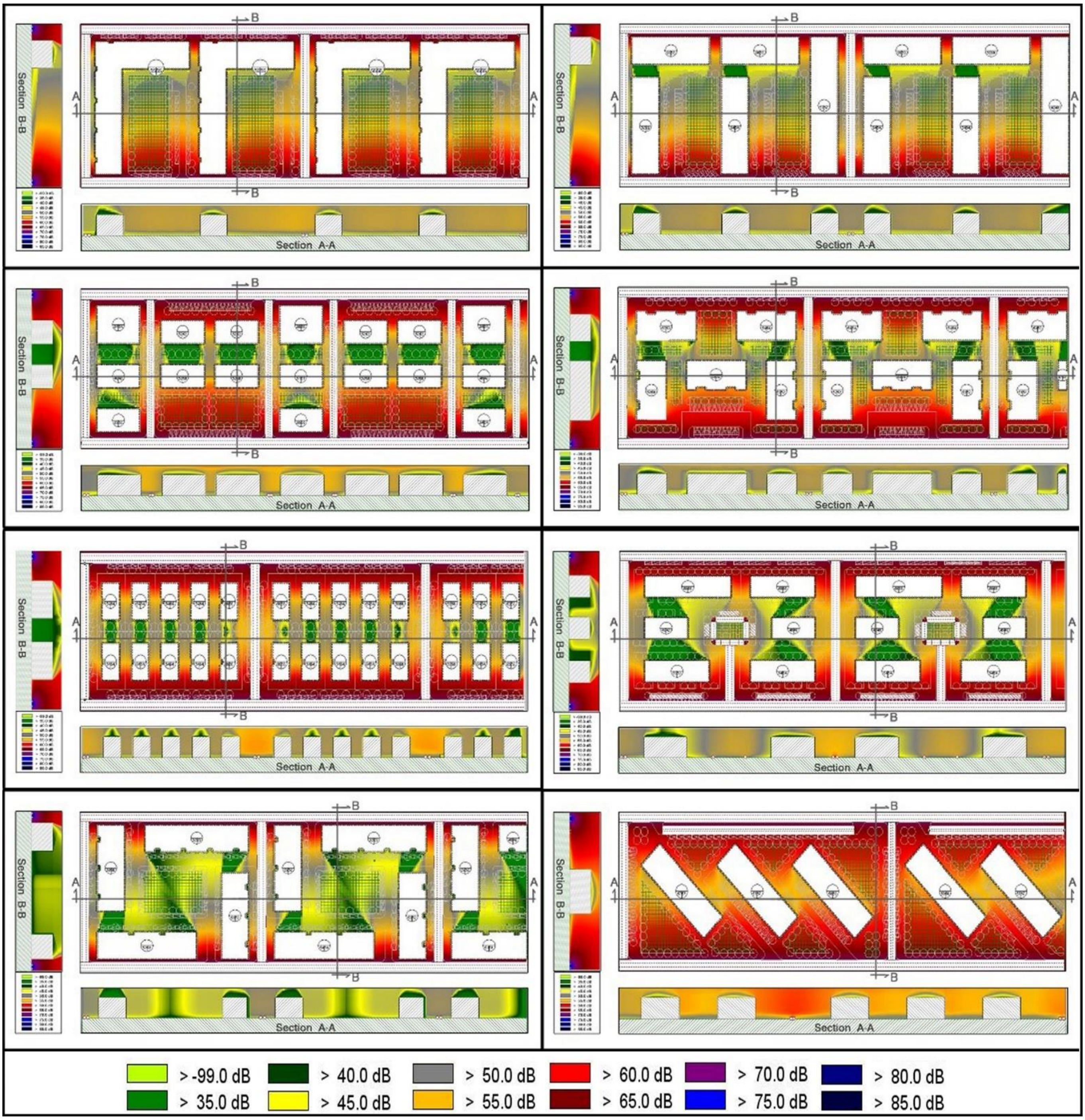


Figure 4.12 Illustration of the noise maps of the chosen urban forms

4.5 Urban form & Urban noise

This study provided eight different urban forms and applied on them five different urban indicators, these urban forms where exposed to noise from sources that have the same properties and conditions, after being referred and adjusted to the same reference area in order to make the comparison possible between them. The propagation of noise in these types of urban forms and their shaping allowed quantifying noise levels on buildings facades and calculating the levels of noise associated with each form.

Table (14), displays the results of urban indicators that have been applied to the eight selected urban forms and the corresponding levels of noise exposure.

Table 14 Results of the urban indicators and the corresponding noise levels

	Noise	Urban Indicators				
Forms	Leq	P	IV	CI	ROS	Form
	dB(A)	(%)	$(m^3)\times 10^{-3}$	(-)	(%)	(-)
1	55.5	30.4	136119.8	0.56	69.6	3.51
2	53.5	36.9	165146.5	0.73	63.1	2.81
3	51.2	25.1	112501.8	0.86	74.9	1.63
4	51.7	29.1	130368.0	0.77	70.9	1.65
5	53.4	20.2	90272.0	0.82	79.8	1.66
6	50.0	23.0	102854.1	0.77	77.0	2.10
7	51.4	36.2	162139.5	0.72	63.8	2.46
8	56.8	16.9	75600.0	0.75	83.1	2.26

CHAPTER 5

5 ANALYSIS AND DISCUSSION

5.1 The Behaviours of Noise Propagation toward the Urban Areas

In order to understand how noise behaves during its transfer from the noise source to the receivers in an urban area, how does the obstacle reduce the propagation of noise, and how to form noise protected areas, this study is going to present eight urban forms that have been referred and adjusted to the same reference area, and exposed to the exact same noise emissions, and it will study the noise behavior in each form, by analyzing the horizontal noise maps and the vertical noise maps, which are represented by colors.

The used scenario of the noise sources for the eight chosen forms to assess this analysis are:

- The noise sources: The two main roads.
- Total number of vehicles in the main roads: 300 vehicles/h.
- Total number of vehicles in the local roads: 0 vehicles/h.
- Speed of vehicle: 50 Km/h.
- Road surface: Smooth asphalt.
- Road gradient: 0%.
- Road traffic flow: Continues fluid.

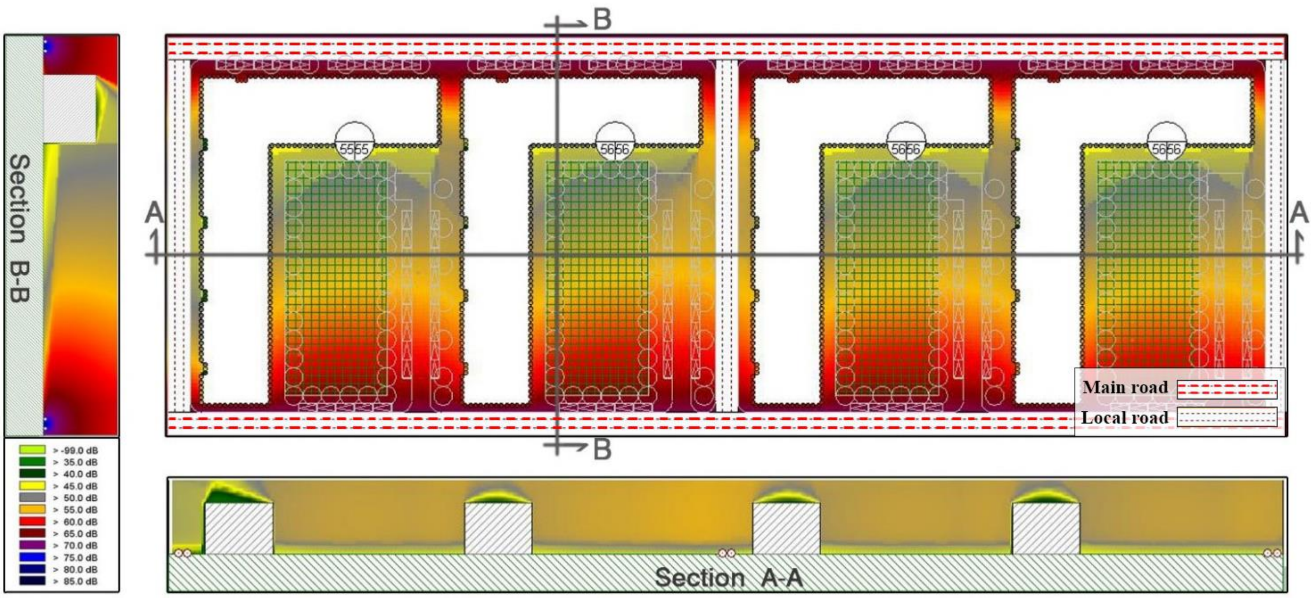


Figure 5.1 Noise maps of urban form 1

From the horizontal map in Figure (5.1), the buildings do not form a noise protected area because the urban area is totally open from the lower side, therefore noise enters easily inside the urban fabric from the lower road. Also, it is seen that the buildings on the upper side almost prevent noise from entering inside the urban fabric from the upper road, and it makes the interior facades with less noise levels. Section B-B reveals the sharp rise in noise levels to which the facades that face the upper road are exposed, and reveals how the distance reduces the noise that the facades are exposed to, from the other source (the lower road).

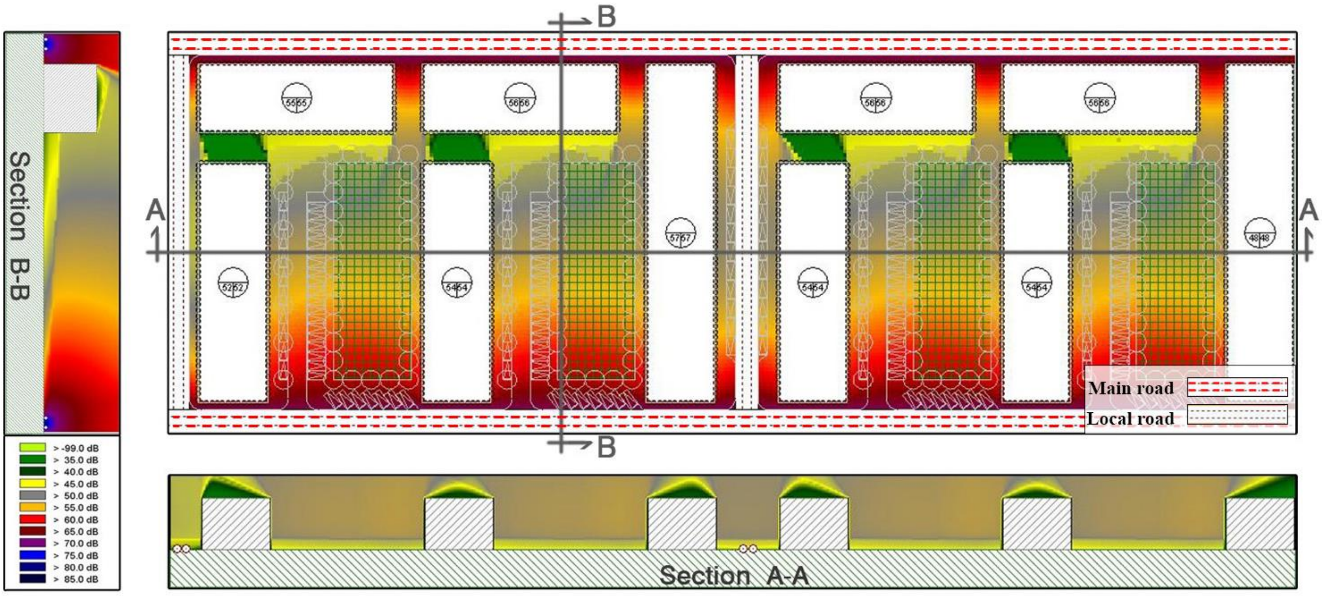


Figure 5.2 Noise maps of urban form 2

The noise propagation in the second form behaves very similarly to its behavior in the first form, as seen in Figure (5.2). From the horizontal noise map, it is seen that the unaligned buildings (perpendicular to the main roads) allow the noise to enter inside the urban fabric, but since the distance between the unaligned buildings is less than it is in the first form, it is noticed that the decrease of this distance reduces the noise that enters into the urban fabric. The aligned buildings (parallel with the main roads) act the same as the buildings act on the upper side of the first urban form. From section B-B it is seen that the noise behaves similarly to the previous behavior even though there are openings between the buildings on the perpendicular side of the urban form to the noise sources, which mean when the buildings openings are perpendicular to the line of the noise source, the increase of noise levels is minimal.

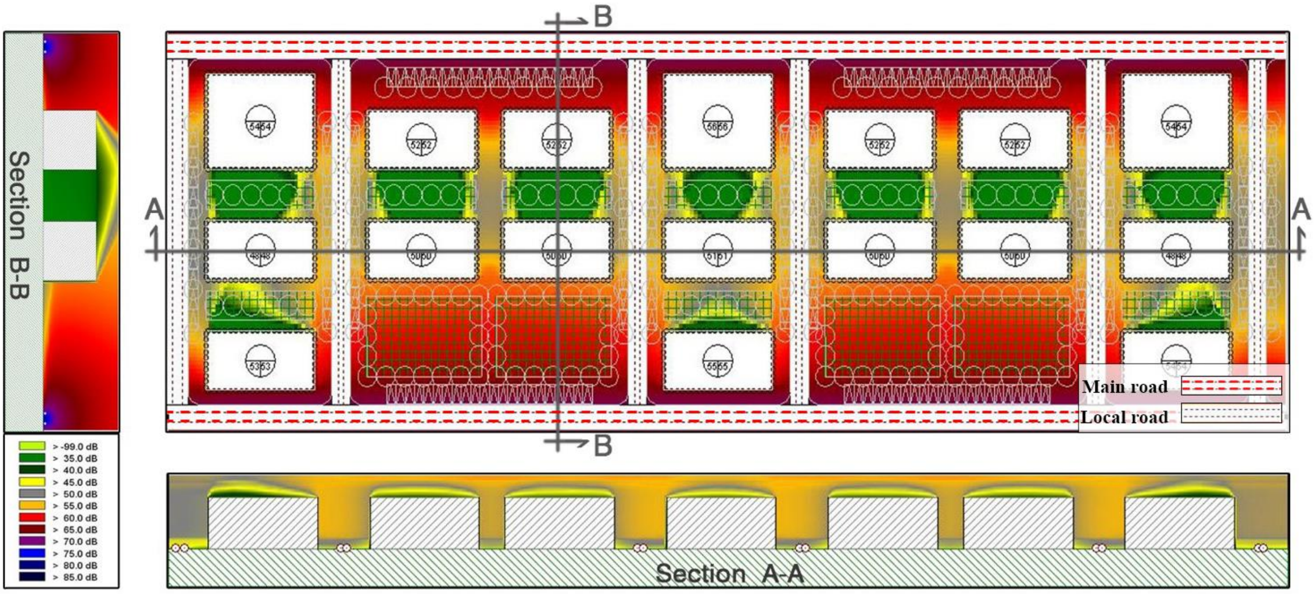


Figure 5.3 Noise maps of urban form 3

As shown in Figure (5.3), the third form creates a number of small noise protected areas, even though there are more noise non-protected areas. Also, it is seen that every building has at least one quiet facade (facade with low noise levels), where section B-B shows the facades with high noise levels and the facades with low noise levels.

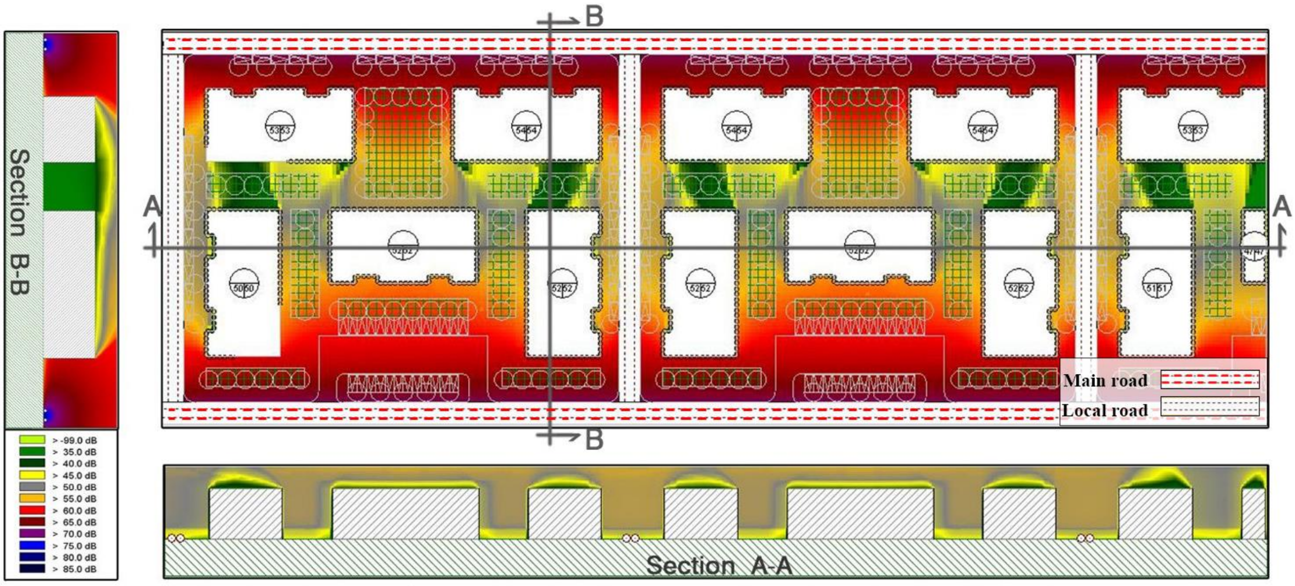


Figure 5.4 Noise maps of urban form 4

In the horizontal map in Figure (5.4), most of the urban areas are exposed to high noise levels because of the big openings between the aligned buildings, and the only noise-protected areas occupy the openings in the unaligned buildings. Even though as seen in the sections, the fourth form provides some quiet facades, because of their positions and their distance from main roads.

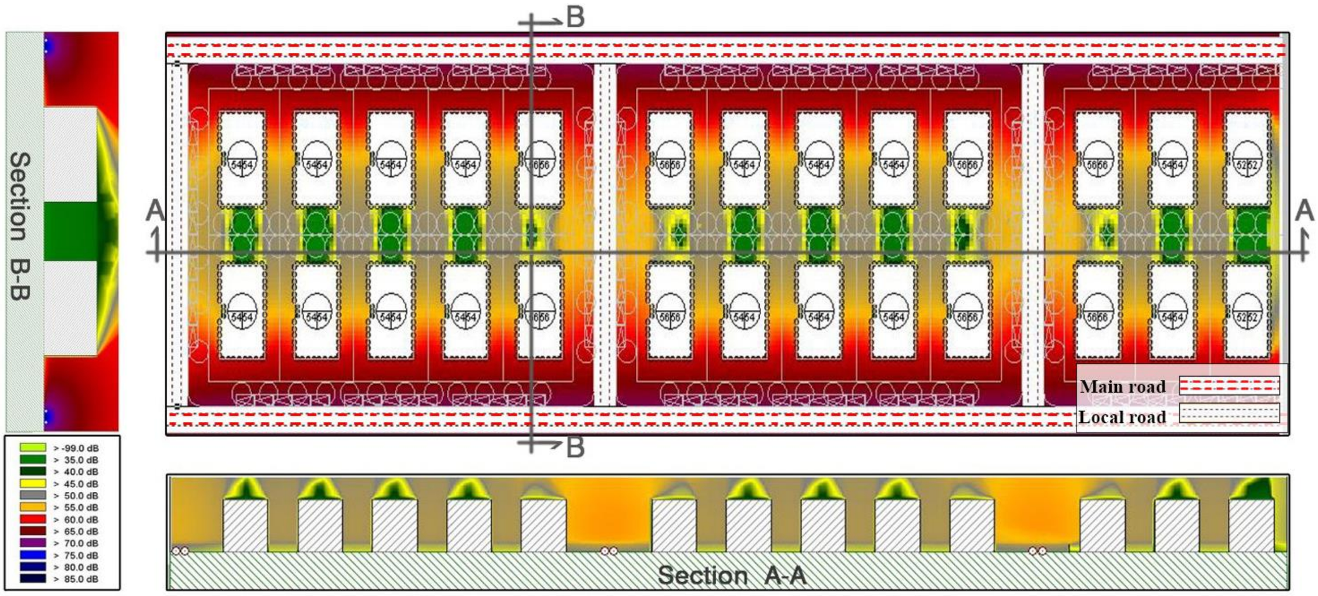


Figure 5.5 Noise maps of urban form 5

As seen in Figure (5.5), noise behaves very similar to its behavior in the third form, but the noise protected areas are smaller than those in the third form, because the buildings in the third form are parallel with the main roads and here they are perpendicular to the road. And the quiet facades in the fifth form are less than those in the third for the same reason.

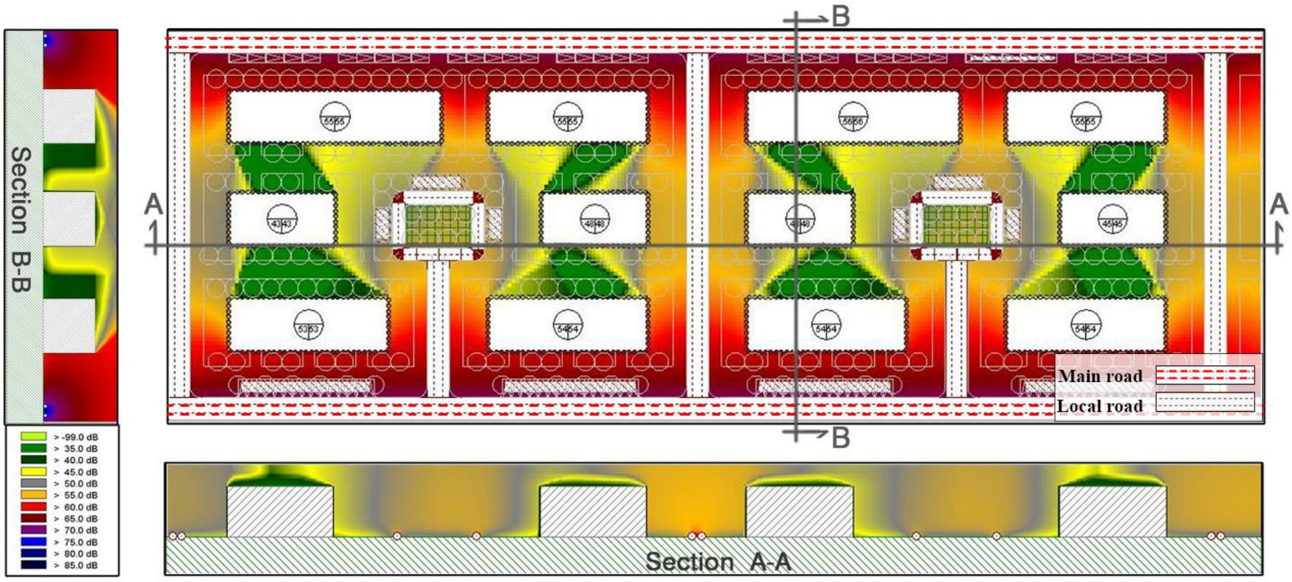


Figure 5.6 Noise maps of urban form 6

As shown in Figure (5.6), the sixth form provides a big noise-protected area and buildings with quiet facades, because all the buildings are parallel to the main roads and most of the openings between the buildings are on the perpendicular side of the urban forms to the noise sources.

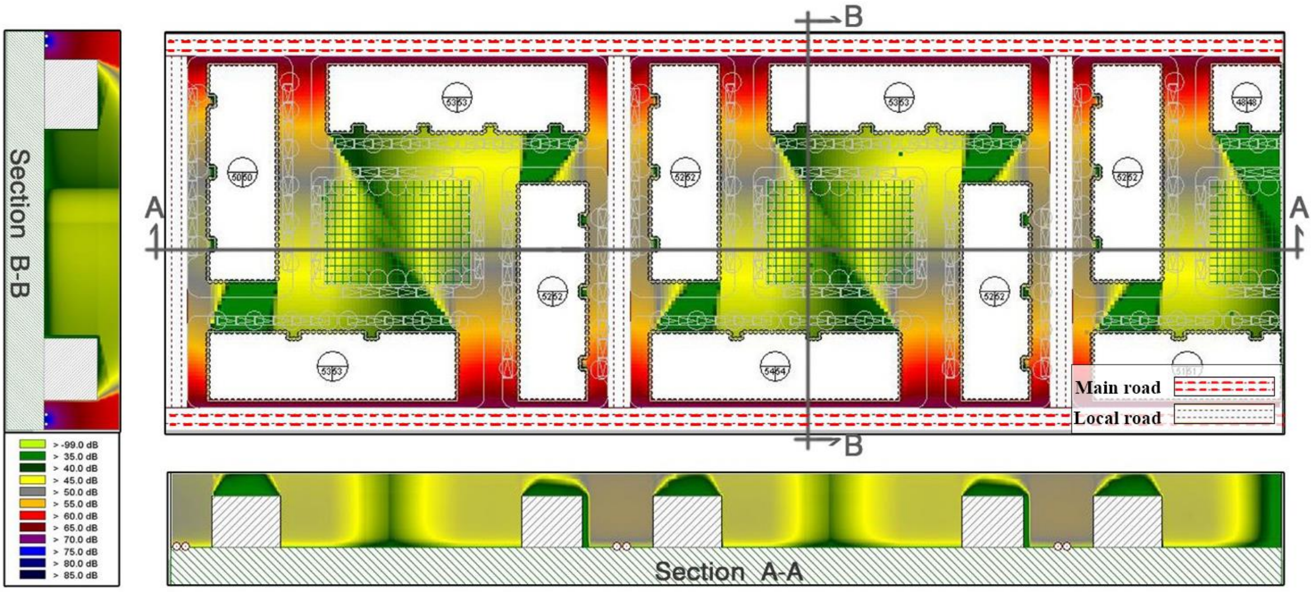


Figure 5.7 Noise maps of urban form 7

The seventh form provides a big noise-protected area as seen in Figure (5.7), because of the close implementation of the buildings with very small openings where the high levels of noise can barely enter inside the urban fabric. Section B-B reveals the sharp rise in noise levels to which the facades that face the main roads are exposed, and reveals a big noise-protected area between the buildings, where the facades that face this area are quiet facades.

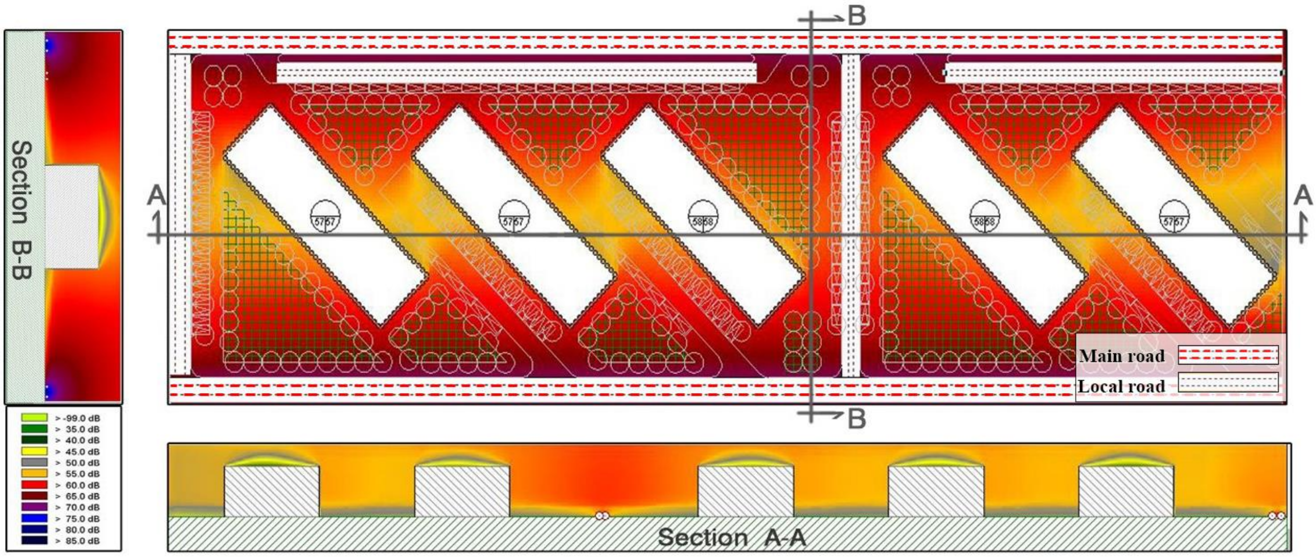


Figure 5.8 Noise maps of urban form 8

From Figure (5.8), it is seen that the eighth urban form with its small number of buildings and their implementation makes the spread of noise from a source to the other source possible because of lack of obstacles, thus, it is possible to say that the permeability is total in the eighth form. However, this type of arrangement is still better than if it was perpendicular to the main roads, and those two types have the highest noise levels, raise more noise areas and all the facades are exposed to high noise levels, as it is seen in the sections and the horizontal map in Figure (5.8).

5.2 The Influence of Urban Form on Noise Propagation

In order to understand the interaction between the urban forms and the propagation of noise levels, and to determine how the urban form may influence on the propagation of urban noise, this study is going to present each urban indicator -the occupation index, the volumetric index, the porosity index, the compactness index, and the form index-, which were applied on the eight selected forms with the corresponding average noise levels of each form, its graph and the respective trend line of these eight forms.

The used scenario of noise sources for the eight chosen forms to assess this analysis are:

- Total number of vehicles in the main roads: 300 vehicles/h.
- Total number of vehicles in the local roads: 0 vehicles/h.
- Speed of vehicle: 50 Km/h.
- Road surface: Smooth asphalt.
- Road gradient: 0%.
- Road traffic flow: Continues fluid.

The Occupation index (P%), Figure (5.8) presents the results of the occupation index for the eight chosen forms, the corresponding average noise levels of each one, its graph and the trend line of these eight forms.

Forms	Leq dB(A)	P (%)
1	55.5	30.4
2	53.5	36.9
3	51.2	25.1
4	51.7	29.1
5	53.4	20.2
6	50.0	23.0
7	51.4	36.2
8	56.8	16.9

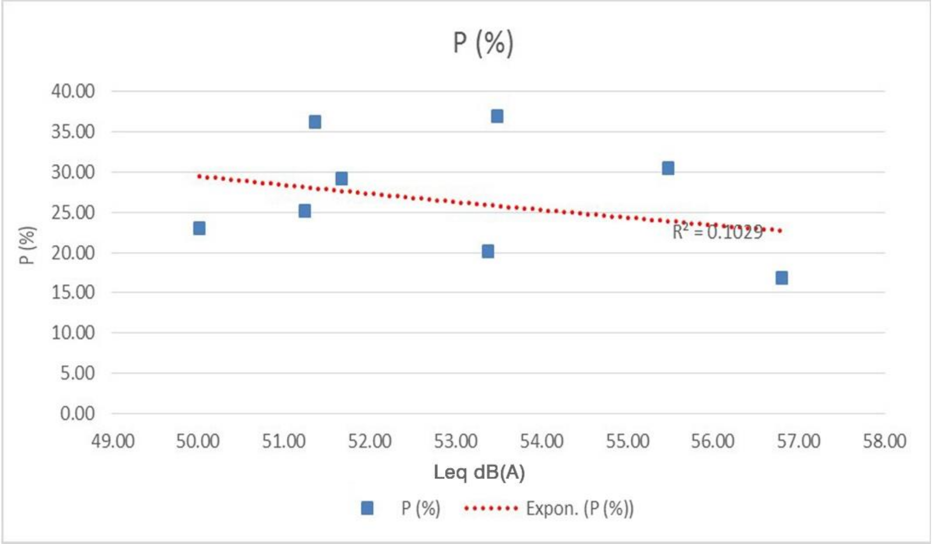


Figure 5.9 Illustration of the relationship between the occupation index and the average noise level

As seen in Figure (5.8), the presented trend line shows that there is an inverse relationship between the occupation index and the noise levels. In other words, the eighth urban form has the lowest occupation index value (P%) but presents the highest noise level. In turn, the urban form number seven has one of the highest occupation index and presents one of the lowest noise levels.

It heavily depends on the urban planning design and the orientation of the buildings, but in general, the more occupation areas are, the more obstacles exist, and a less area for the noise to propagate. In addition, the increase of the occupation area intensifies the possibility to form protected areas in order to reduce the noise that enters into the urban fabric. Thus, it is possible to say that when the occupation index decreases the noise level increase, and when the occupation index increases the noise level decrease.

The volumetric index (IV), Figure (5.9) presents the results of the volumetric index for the eight chosen forms, the corresponding average noise levels of each form, its graph and the trend line of these eight forms.

Forms	Leq dB(A)	IV $(m^3) \times 10^{-3}$
1	55.5	136119.8
2	53.5	165146.5
3	51.2	112501.8
4	51.7	130368.0
5	53.4	90272.0
6	50.0	102854.1
7	51.4	162139.5
8	56.8	75600.0

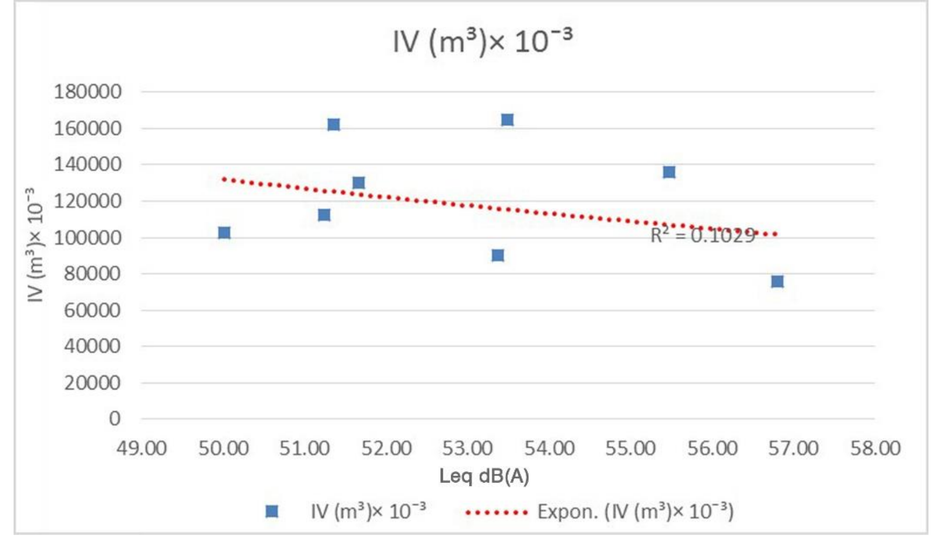


Figure 5.10 Illustration of the relationship between the volumetric index and the average noise level

From Figure (5.9), it is seen that the volumetric index (IV) has the same behavior as the occupation index (P%) toward the noise levels. The urban form number eight has the lowest volumetric index value (IV) but presents the highest noise level, and the seventh form has one of the highest volumetric indexes and presents one of the lowest noise level. Thus, for the exact same reasons of the inverse relationship between the occupation index and the noise level, it is possible to conclude that when the volumetric index decreases the noise level increases.

The porosity index (ROS), Figure (5.10) presents the results of the porosity index for the eight chosen forms, the corresponding average noise levels of each form, its graph and the trend line of these eight forms.

Forms	Leq dB(A)	ROS (%)
1	55.5	69.6
2	53.5	63.1
3	51.2	74.9
4	51.7	70.9
5	53.4	79.8
6	50.0	77.0
7	51.4	63.8
8	56.8	83.1

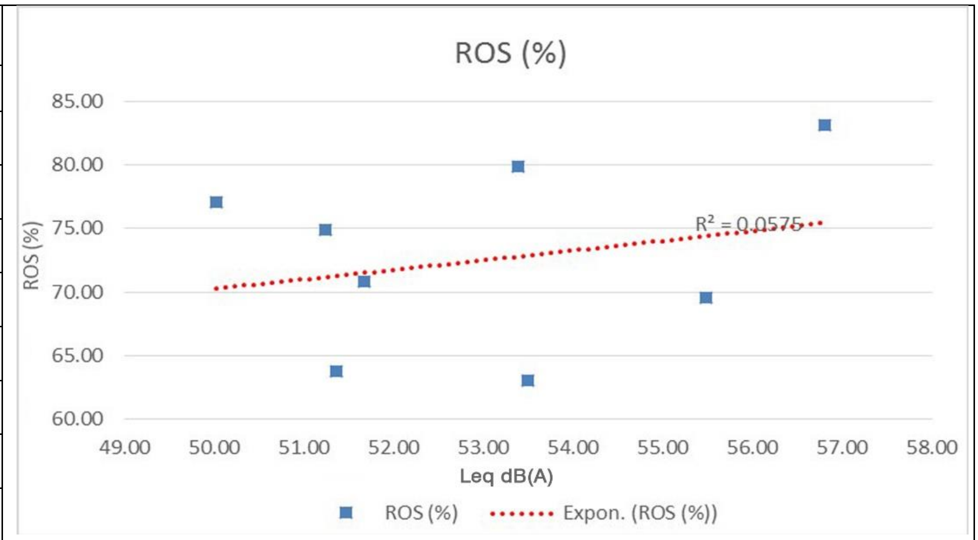


Figure 5.11 Illustration of the relationship between the porosity index and the average noise level

According to the behavior of the presented trend line in Figure (5.10), it is seen that there is a proportional relationship between the noise levels and the porosity index (ROS), which presents the ratio of open spaces or non-build areas. The eighth form has the highest (ROS) value and presents the highest rate of noise level. In turn, the seventh form has one of the lowest porosity index values and presents one of the lowest rates of noise level. The more the permeability of an urban area is, the fewer obstacles exist to keep the noise waves from reaching the building facades. As the porosity index increases the noise level increases.

The compactness index (CI), Figure (5.11) presents the results of (CI) for the eight chosen urban forms, the corresponding average noise levels of each urban form, its graph and the trend line of these forms.

Forms	Leq dB(A)	CI (-)
1	55.5	0.56
2	53.5	0.73
3	51.2	0.86
4	51.7	0.77
5	53.4	0.82
6	50.0	0.77
7	51.4	0.72
8	56.8	0.75

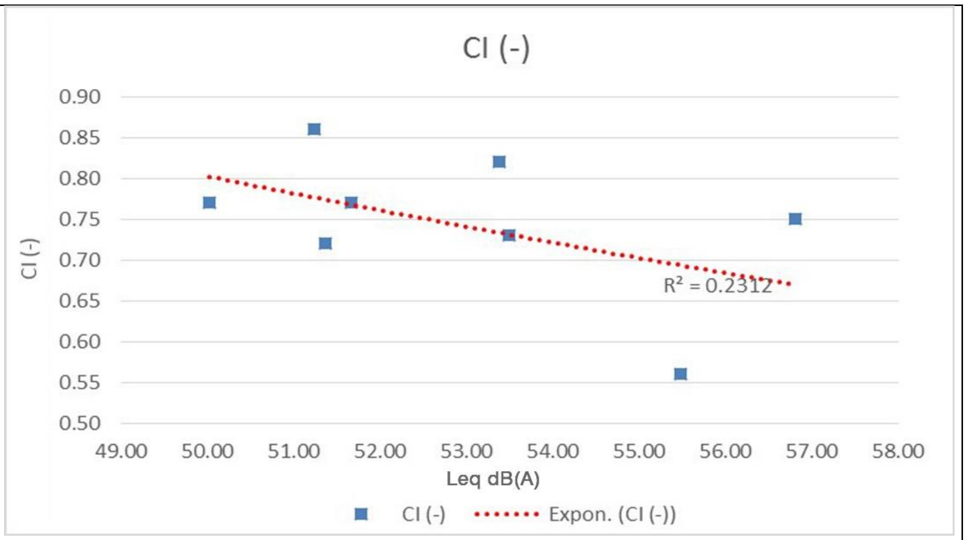


Figure 5.12 Illustration of the relationship between the compactness index and the average noise level

The compactness index (CI) is an index that measures the patch shape and measures the fragmentation of the entire urban land space. It is directly related to the regularity and irregularity of the patches shapes. However, since the chosen forms in this study all have regular and linear shapes except the first one, the results achieved in this study must be analysed carefully.

In general, when there are more irregular buildings shapes in the urban area the possibility of forming noise shadows zones (low noise zone) increase, and the compactness index (CI) decreases. Therefore, it was expected that with the increase of (CI) the average noise level on the facades of the buildings will increase.

The form index (Form), Figure (5.12) presents the results of the form index for the eight chosen forms, the corresponding average noise levels of each form, its graph and the trend line of these eight forms.

Forms	Leq dB(A)	Form (-)
1	55.5	3.51
2	53.5	2.81
3	51.2	1.63
4	51.7	1.65
5	53.4	1.66
6	50.0	2.1
7	51.4	2.46
8	56.8	2.26

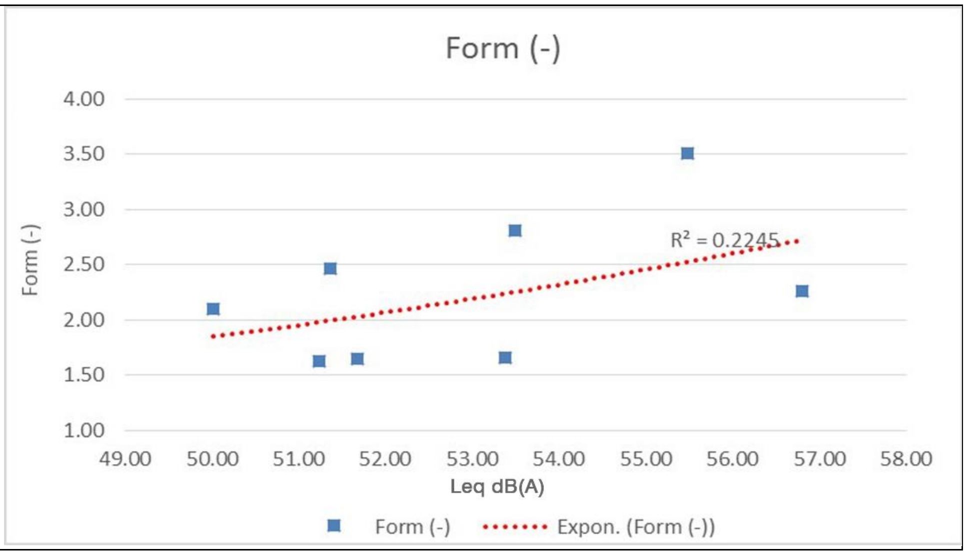


Figure 5.13 Illustration of the relationship between the form index and the average noise level

The Form Index is an index that characterizes the complexity of an urban area perimeter through the relationship between the perimeter and the area, it studies the extension or length of forms, the longer the form is the higher the form index value will be. The trend line in Figure (5.12) shows the proportional relationship between noise levels and form index (Form), in other words, the higher the form index value is the higher the noise level will be. However, long forms have the ability to create noise-protected areas more than short forms, but that depends on buildings positions and orientation in relation to the roads, since roads are the noise sources.

In order to clarify the relation between form index and noise level, the study will consider two groups of urban forms with their tables, graphs, and trend lines.

The first group includes the three urban forms that have the lowest form index values (form 3, 4, and 5), and two forms with high form index values and their implementation provide noise-protected areas (form 6 and 7). The second group includes the same three urban forms, with the lowest form index values, and the other two forms that also have high form index value but their implementation do not provide noise protected areas (form 2 and 8).

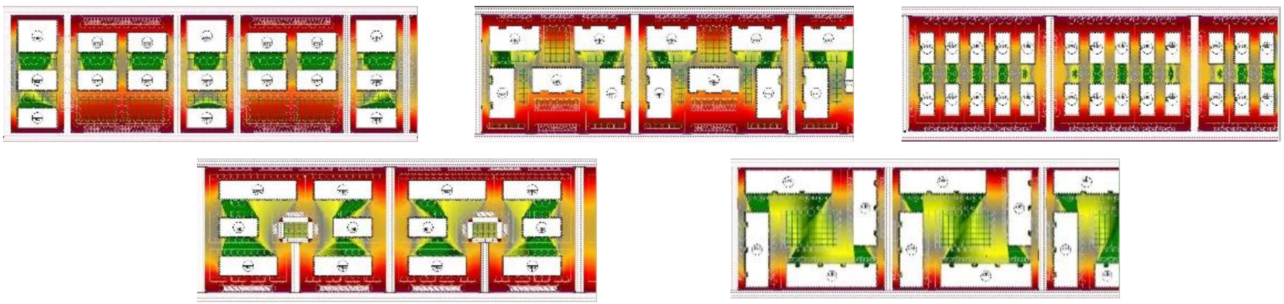


Figure 5.14 Form index first group (forms 3,4,5,6 and 7)

1st Group Forms	Leq dB(A)	Form (-)
3	51.3	1.63
4	51.7	1.65
5	53.4	1.66
6	50.0	2.1
7	51.4	2.46

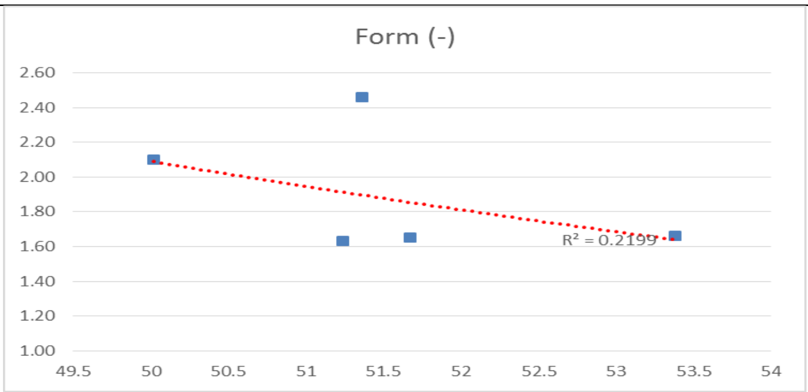


Figure 5.15 Illustration of the relationship between the first form index group and the average noise level

From Figure (5.13) and the trend line behavior in Figure (5.14), it is possible to say that when the buildings positions in relation with the noise source provide noise-protected areas, then the higher the 'form index' is the lower the noise levels on the facades are. In this case, because the longer are the buildings, the quietest are the facades.

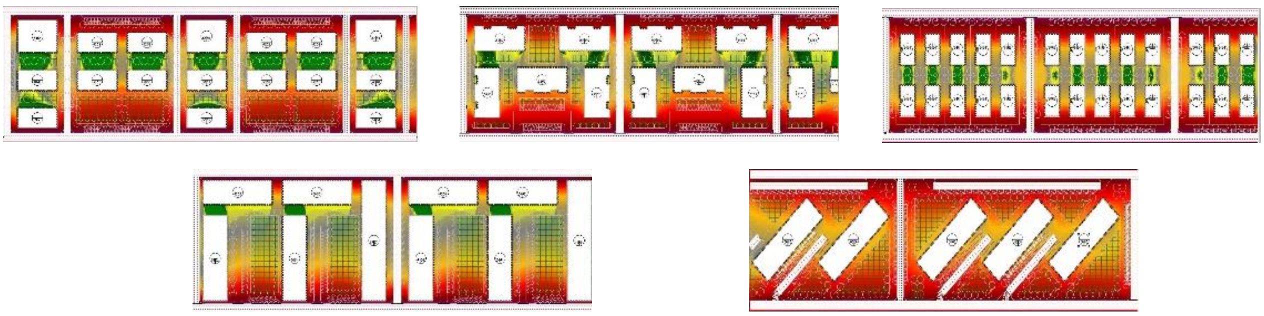


Figure 5.16 Form index second group (forms 2,3,4,5 and 8)

2nd Group Forms	Leq dB(A)	Form (-)
2	53.5	2.81
3	51.2	1.63
4	51.7	1.65
5	53.4	1.66
8	56.8	2.26

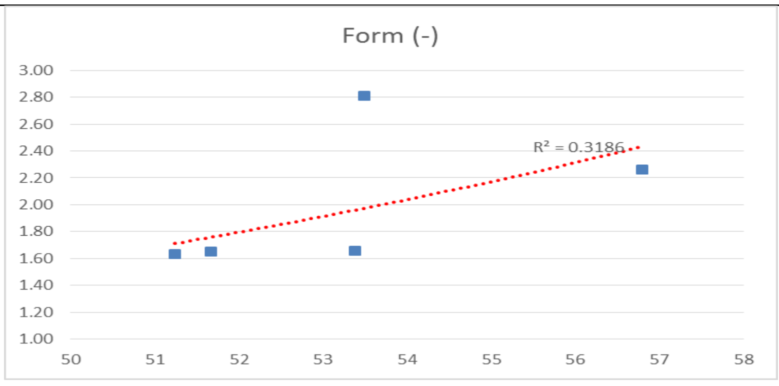


Figure 5.17 Illustration of the relationship between the second group form index and the average noise level

From Figure (5.15) and the trend line behavior in Figure (5.16), it is possible to say that when the buildings positions in relation with the noise source do not provide noise-protected areas, then the higher the ‘form index’ is, the higher the noise levels on the buildings facades are. In this case, because the longer the buildings are, the facades are more exposed to high noise levels.

5.3 The influence of speed of vehicles on noise propagation

In order to understand the influence of the variation of vehicles speeds on noise propagation and its levels on buildings facades, this study presents the application of three scenarios of different vehicles speed on the eight chosen urban forms. The average noise levels generated from these scenarios, the results of the urban indicators calculation, the graphs and the respective trend lines of these eight forms are presented below.

The three scenarios developed to assess this analysis have the following characteristics:

- Total number of vehicles in the main roads: 300 vehicles/h.
- Speed of vehicles: - 40 Km/h.
  - 50 Km/h.
  - 60 Km/h.
- Road surface: Smooth asphalt.
- Road gradient: 0%.
- Road traffic flow: Continues fluid.

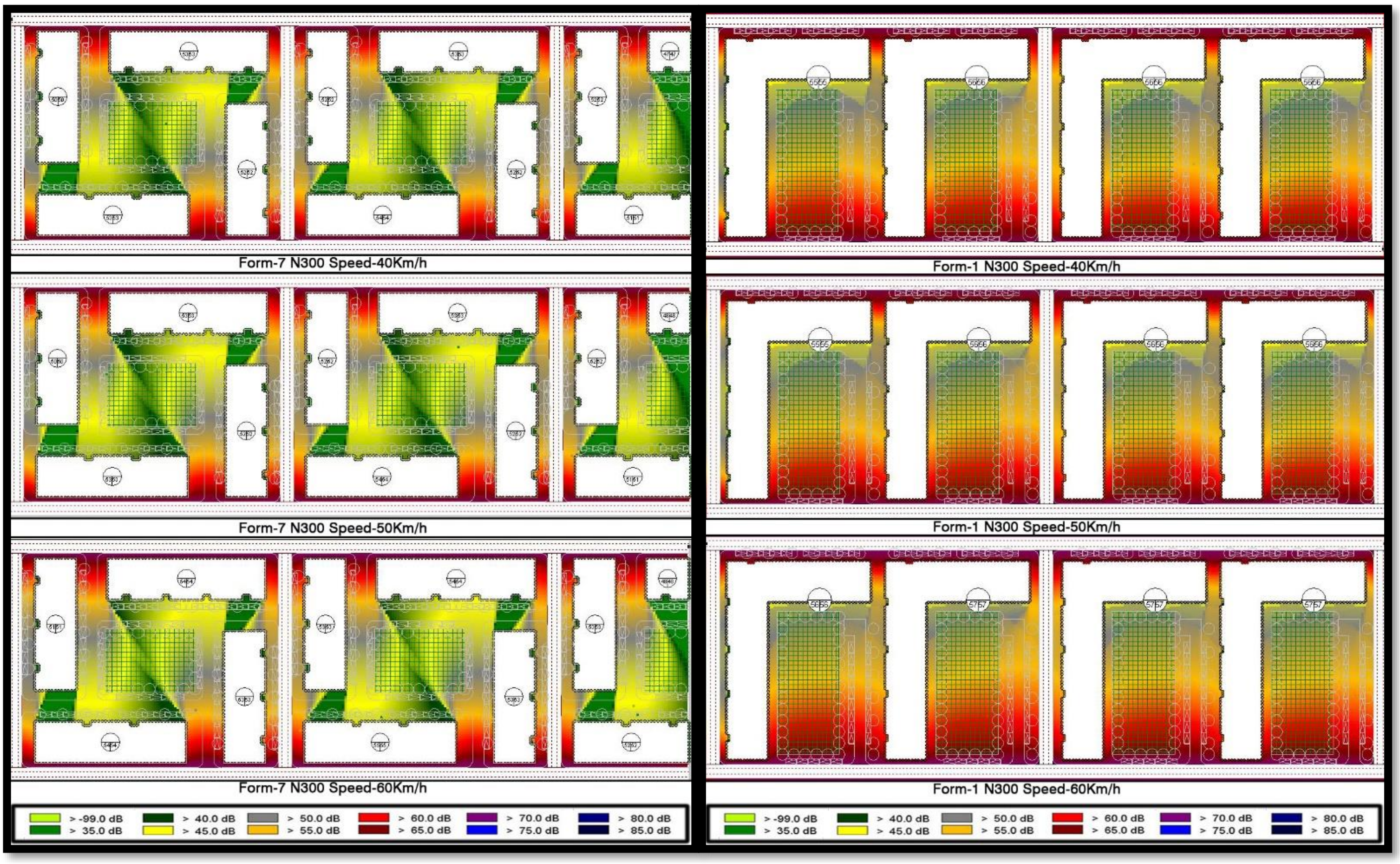


Figure 5.18 The noise behavior according to the speed variation in the first and the seventh form

The effects of the variation of speed can be seen in Figure (5.17). The difference between the noise levels generated from the speed of 40Km/h and 50Km/h is not very clear, however that difference is more noticeable at the speed of 60 Km/h. To assess the influence of the speed variation on the noise levels more clearly, the study will present the results of noise levels on the buildings facades in relation with this variation, with the corresponding urban indicators results.

Table 15 The results of noise levels on the buildings facades in relation with the speed variation

Forms	Noise Levels Leq dB(A)			Urban Indicators				
	40 Km/h	50 Km/h	60 Km/h	P (%)	IV (m³)× 10^{-3}	CI (-)	ROS (%)	Form (-)
1	55.4	55.5	56.4	30.4	136119.8	0.56	69.6	3.51
2	53.4	53.5	54.5	36.9	165146.5	0.73	63.1	2.81
3	51.2	51.2	52.2	25.1	112501.8	0.86	74.9	1.63
4	51.6	51.7	52.6	29.1	130368.0	0.77	70.9	1.65
5	53.3	53.4	54.3	20.2	90272.0	0.82	79.8	1.66
6	49.9	50.0	50.9	23.0	102854.1	0.77	77.0	2.1
7	51.3	51.4	52.3	36.2	162139.5	0.72	63.8	2.46
8	56.7	56.8	57.7	16.9	75600.0	0.75	83.1	2.26

From Table (15) it is seen that the differences between the generated noise levels from the speed of 40 Km/h and 50 Km/h are less than 0.1 dB(A), and that is why it was not noticed from the noise maps in Figure (5.17). However the differences between the speed of 50 Km/h and 60 Km/h are about 1 dB (A), and it was hardly observed from the noise maps.

In order to find a relation between urban indicators and speed variation, the study is going to present the results of the urban indicators for the eight urban forms, the corresponding average noise levels generated from the speed variation scenarios - the results of the speed of 50Km/h was previously presented to assess the previous analysis-, their graphs and trend lines, as following.

The results of the occupation index (P %) for the eight urban forms, with the previously described procedure are presented in Figures (5.18 and 5.19).

Forms	Leq dB(A)	P (%)
1	55.4	30.4
2	53.4	36.9
3	51.2	25.1
4	51.6	29.1
5	53.3	20.2
6	49.9	23.0
7	51.3	36.2
8	56.7	16.9

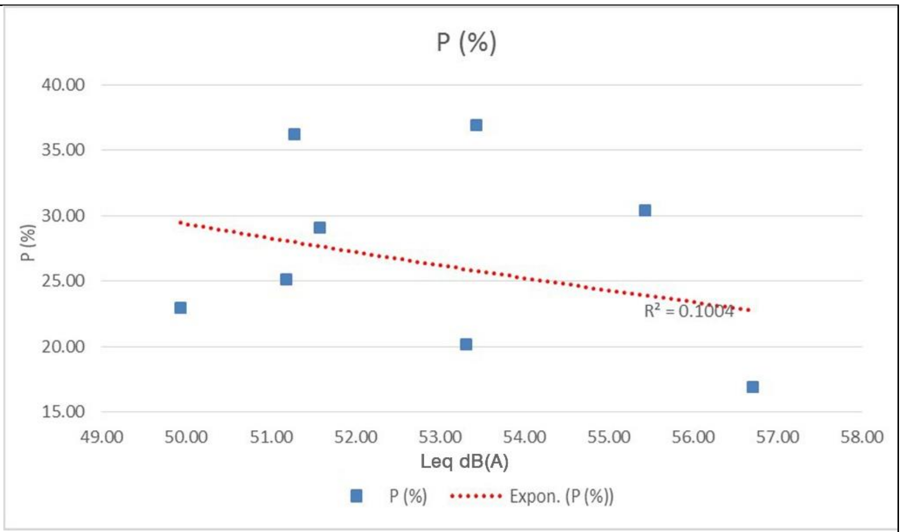


Figure 5.19 Illustration of the relationship between the occupation index and the average noise level
Speed scenario 40 Km/h

Forms	Leq dB(A)	P (%)
1	56.4	30.4
2	54.5	36.9
3	52.2	25.1
4	52.6	29.1
5	54.3	20.2
6	50.9	23.0
7	52.3	36.2
8	57.7	16.9

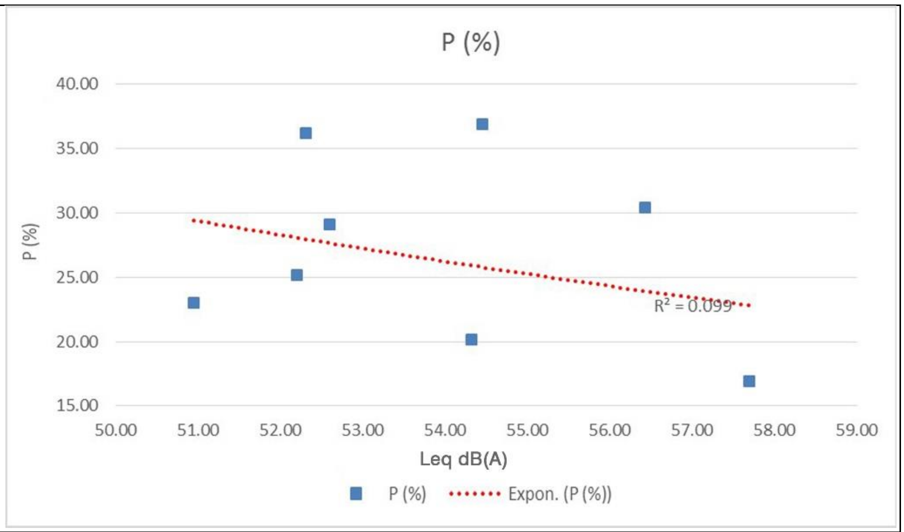


Figure 5.20 Illustration of the relationship between the occupation index and the average noise level Speed scenario 60 Km/h

The results of the volumetric index (IV) for the eight urban forms, the corresponding average noise levels generated from the speed variation scenarios, their graphs, and trend lines presented in Figures (5.20 and 5.21).

Forms	Leq dB(A)	IV $(m^3)\times 10^{-3}$
1	55.4	136119.8
2	53.4	165146.5
3	51.2	112501.8
4	51.6	130368.0
5	53.3	90272.0
6	49.9	102854.1
7	51.3	162139.5
8	56.7	75600.0

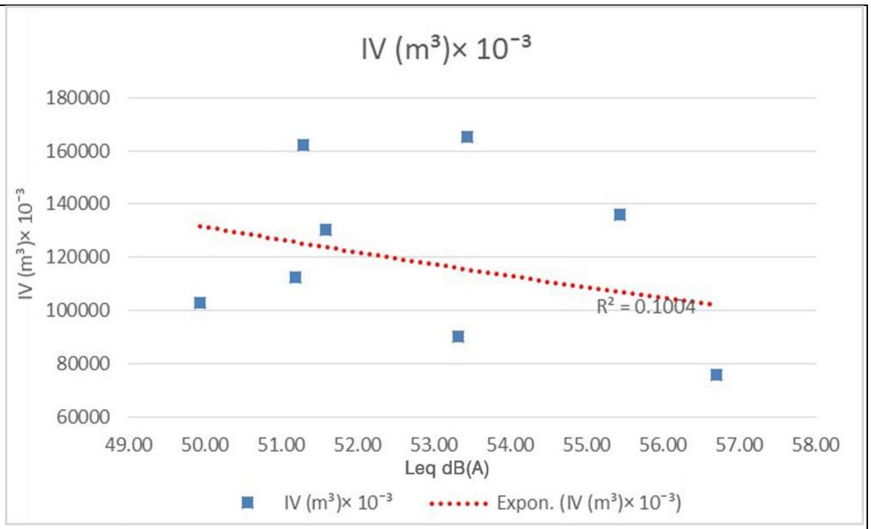


Figure 5.21 Illustration of the relationship between the volumetric index and the average noise level Speed scenario 40 Km/h

Forms	Leq dB(A)	IV $(m^3)\times 10^{-3}$
1	56.4	136119.8
2	54.5	165146.5
3	52.2	112501.8
4	52.6	130368.0
5	54.3	90272.0
6	50.9	102854.1
7	52.3	162139.5
8	57.7	75600.0

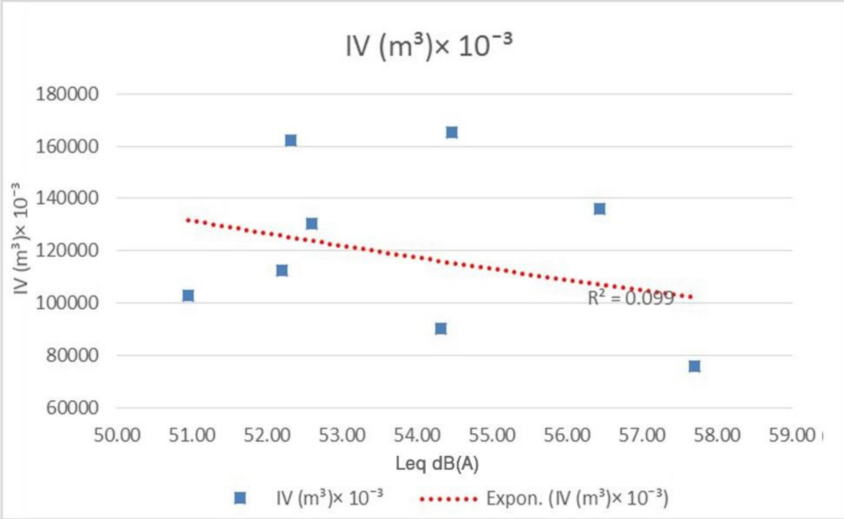


Figure 5.22 Illustration of the relationship between the volumetric index and the average noise level
Speed scenario 60 Km/h

Figures (5.22 and 5.23) present the results of the porosity index (ROS), the corresponding average noise levels generated from speed variation scenarios (40Km/h, 60Km/h), their graphs, and trend lines.

Forms	Leq dB(A)	ROS (%)
1	55.4	69.6
2	53.4	63.1
3	51.2	74.9
4	51.6	70.9
5	53.3	79.8
6	49.9	77.0
7	51.3	63.8
8	56.7	83.1

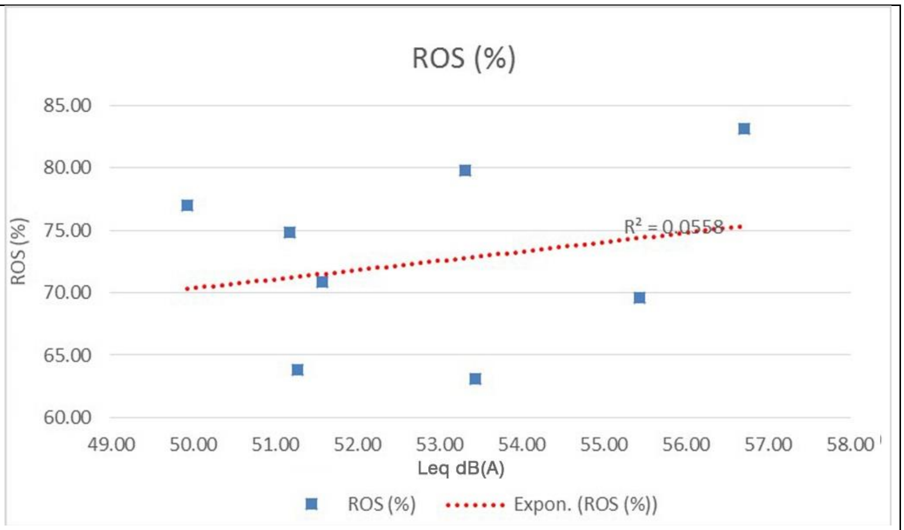


Figure 5.23 Illustration of the relationship between the porosity index and the average noise level
Speed scenario 40 Km/h

Forms	Leq dB(A)	ROS (%)
1	56.4	69.6
2	54.5	63.1
3	52.2	74.9
4	52.6	70.9
5	54.3	79.8
6	50.9	77.0
7	52.3	63.8
8	57.7	83.1

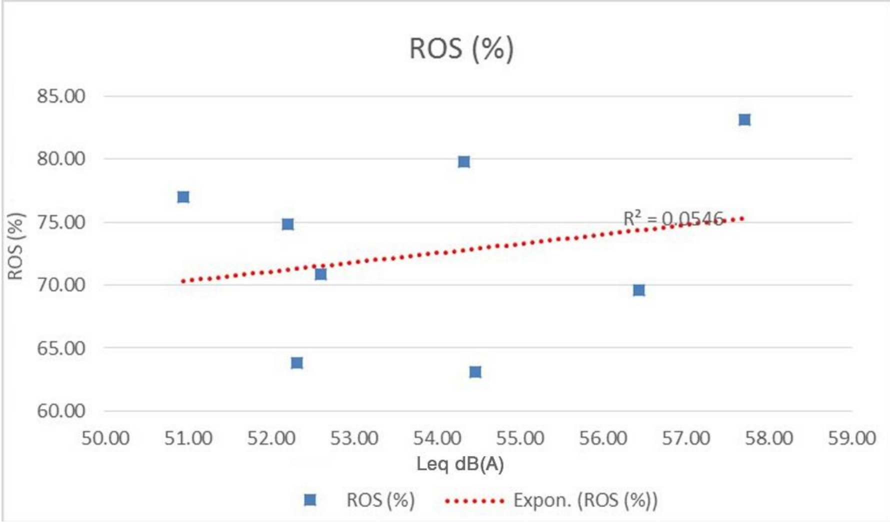


Figure 5.24 Illustration of the relationship between the porosity index and the average noise level
Speed scenario 60 Km/h

The results of the compactness index(CI), the corresponding average noise levels generated from the speed variation scenarios, their graphs, and trend lines presented in Figures (5.24 and 5.25).

Forms	Leq dB(A)	CI (-)
1	55.4	0.56
2	53.4	0.73
3	51.2	0.86
4	51.6	0.77
5	53.3	0.82
6	49.9	0.77
7	51.3	0.72
8	56.7	0.75

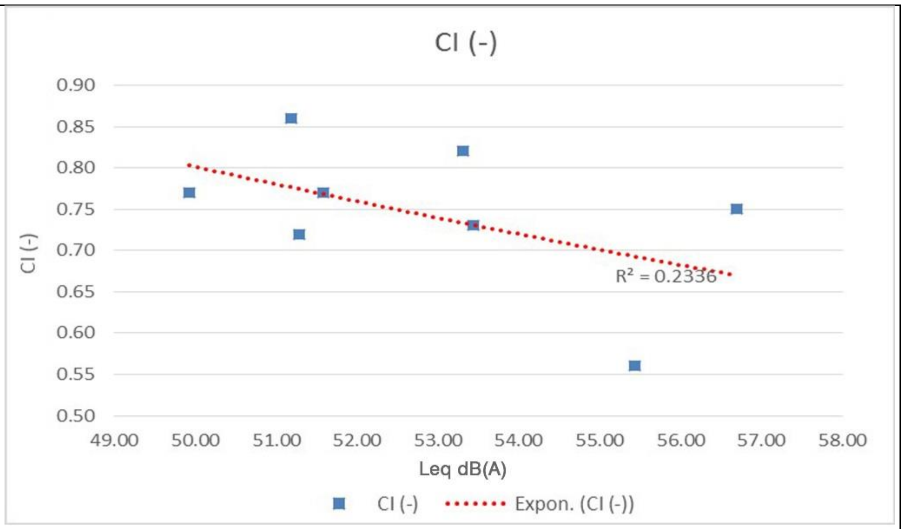


Figure 5.25 Illustration of the relationship between the compactness index and the average noise level
Speed scenario 40 Km/h

Forms	Leq dB(A)	CI (-)
1	56.4	0.56
2	54.5	0.73
3	52.2	0.86
4	52.6	0.77
5	54.3	0.82
6	50.9	0.77
7	52.3	0.72
8	57.7	0.75

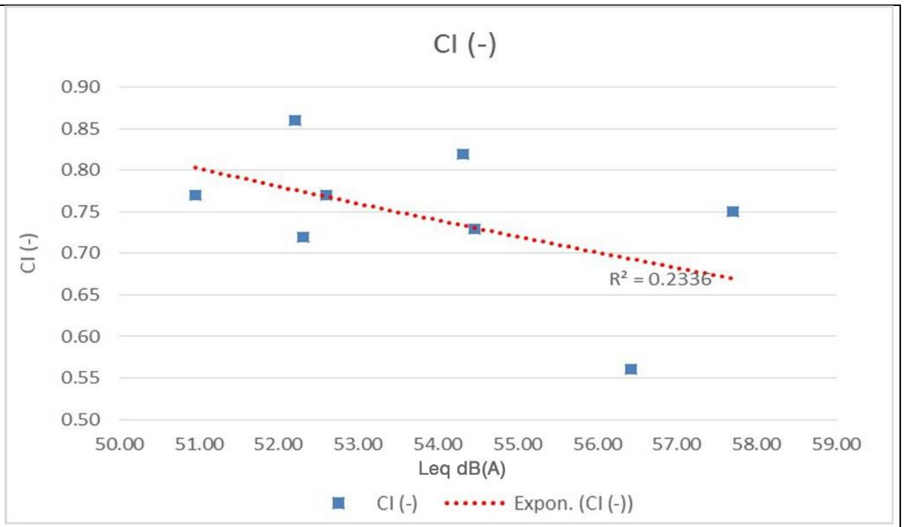
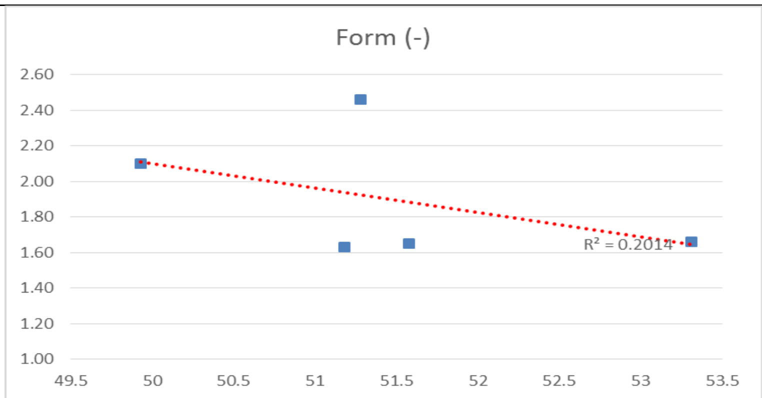


Figure 5.26 Illustration of the relationship between the compactness index and the average noise level
Speed scenario 60 Km/h

Figures (5.26 and 5.27) present the results of the form index (Form) for the previous two divided groups of forms, the corresponding average noise levels generated from speed variation scenarios (40Km/h, 60Km/h), their graphs and trend lines.

1st Group Forms	Leq dB(A)	Form (-)
3	51.2	1.63
4	51.6	1.65
5	53.3	1.66
6	49.9	2.1
7	51.3	2.46



2nd Group Forms	Leq dB(A)	Form (-)
2	53.4	2.81
3	51.2	1.63
4	51.6	1.65
5	53.3	1.66
8	56.7	2.26

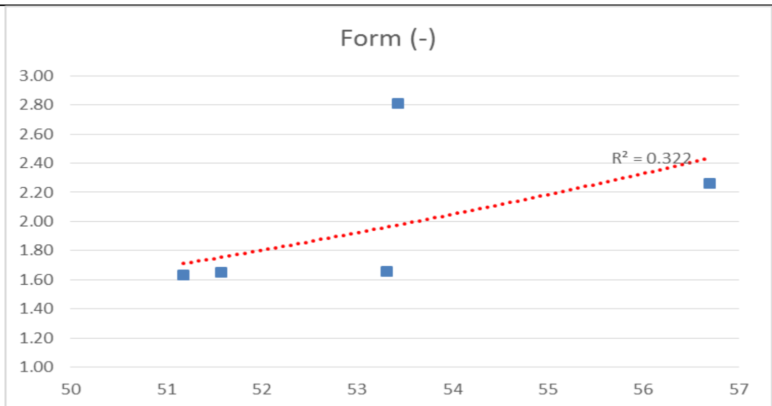
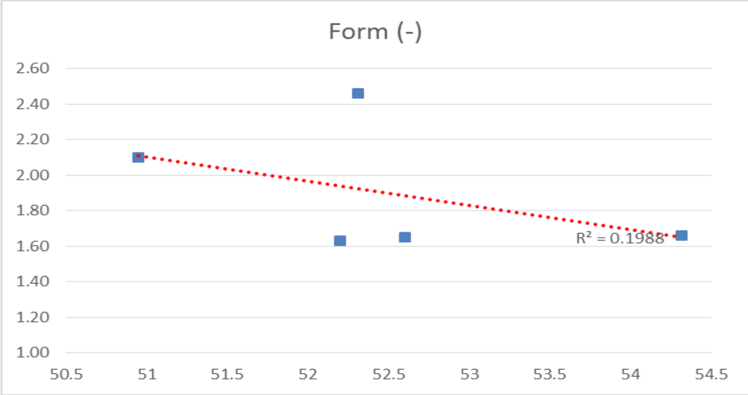


Figure 5.27 Illustration of the relationship between the form index and the average noise level
Speed scenario 40 Km/h

1st Group Forms	Leq dB(A)	Form (-)
3	52.2	1.63
4	52.6	1.65
5	54.3	1.66
6	50.9	2.1
7	52.3	2.46



2nd Group Forms	Leq dB(A)	Form (-)
2	54.5	2.81
3	52.2	1.63
4	52.6	1.65
5	54.3	1.66
8	57.7	2.26

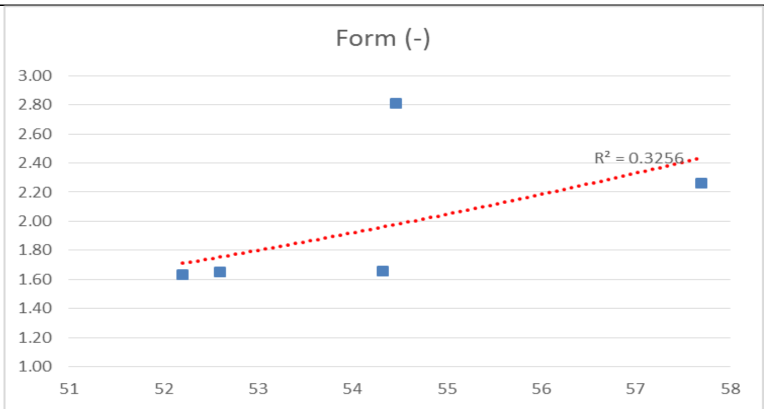


Figure 5.28 Illustration of the relationship between the form index and the average noise level Speed scenario 60 Km/h

From the previous figures which aimed to find a relationship between the urban indicators and the speed variation scenarios, it is seen that a small variation occurred in R^2 when the speed of vehicles vary. It is found that with the increase of the vehicles speed the R^2 increases, which means that the relationship between noise levels on buildings facades and urban form indicators is higher when the speed of vehicles increases.

5.4 The influence of number of vehicles on noise propagation

In order to understand the influence of the variation in the number of vehicles on noise propagation and its levels on the buildings facades, this study presents the application of three scenarios of different numbers of vehicles on the eight urban forms. The average noise levels generated from these scenarios, the results of urban indicators calculation, their graphs and their respective trend lines of these eight forms are presented below.

The three scenarios developed to assess this analysis have the following characteristics:

- Total number of vehicles in the main roads:
  - 200 vehicles/h.
  - 300 vehicles/h.
  - 400 vehicles/h.
- Speed of vehicle: 50 Km/h.
- Road surface: Smooth asphalt.
- Road gradient: 0%.
- Road traffic flow: Continues fluid.

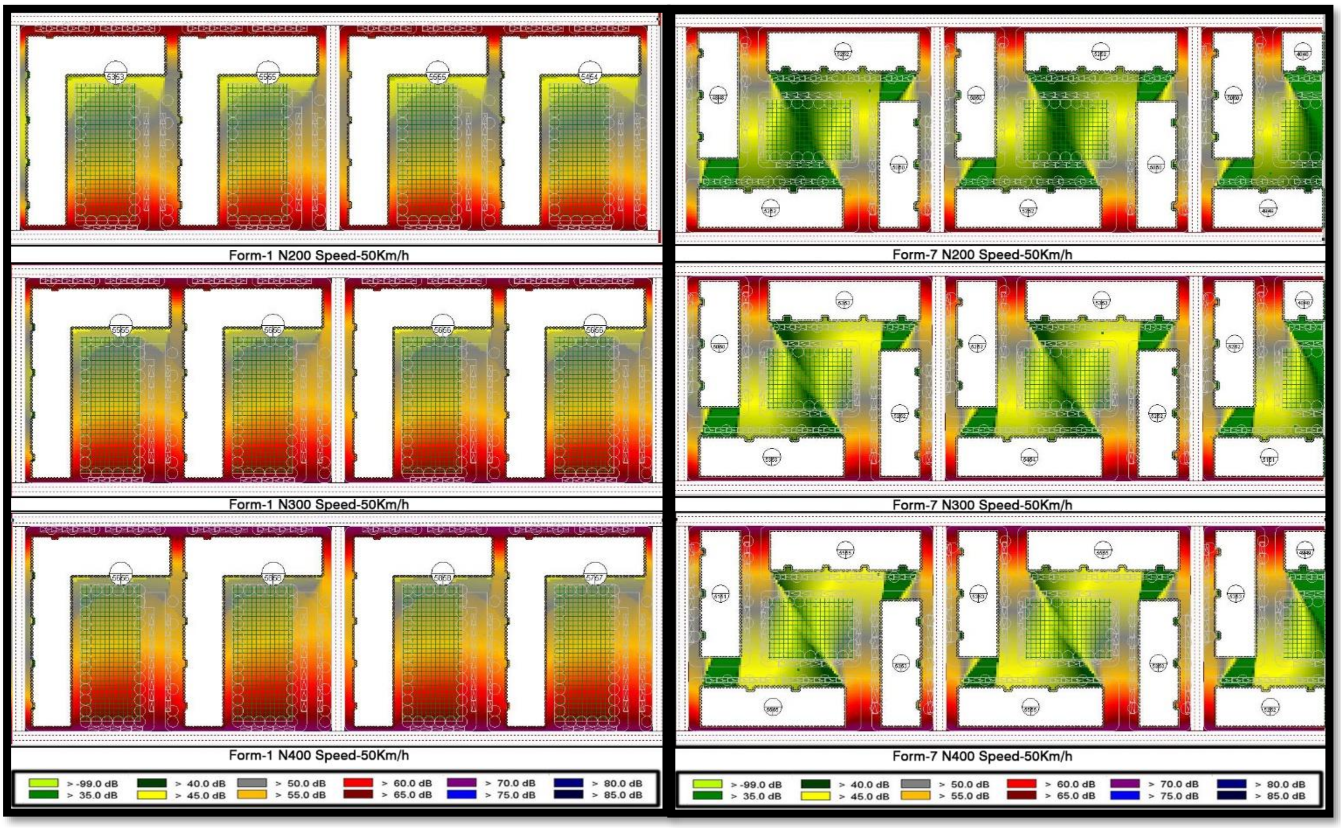


Figure 5.29 The noise behavior according to the variation in the number of vehicles in the first and the seventh form

The effects of the variation in the number of vehicles on the noise propagation can be observed from the noise maps, as seen in Figure (5.28), thus, it is possible to say that the greater the number of vehicles is the greater noise levels are in the urban fabric.

Table (16) shows the numerical results of noise levels on the buildings facades in relation with the variation in the number of vehicles, with the corresponding urban indicators results.

Table 16 The results of noise levels on the facades in relation with the variation in the number of vehicles

Forms	Noise Levels			Urban Indicators				
	Leq dB(A)			P	IV	CI	ROS	Form
	200 vehicles/h	300 vehicles/h	400 vehicles/h	(%)	$(m^3)\times 10^{-3}$	(-)	(%)	(-)
1	53.7	55.5	56.7	30.4	136119.8	0.56	69.6	3.51
2	51.7	53.5	54.7	36.9	165146.5	0.73	63.1	2.81
3	49.5	51.2	52.0	25.1	112501.8	0.86	74.9	1.63
4	51.3	51.7	52.9	29.1	130368.0	0.77	70.9	1.65
5	51.6	53.4	54.6	20.2	90272.0	0.82	79.8	1.66
6	48.7	50.0	51.7	23.0	102854.1	0.77	77.0	2.1
7	49.6	51.4	52.1	36.2	162139.5	0.72	63.8	2.46
8	55.9	56.8	58.4	16.9	75600.0	0.75	83.1	2.26

From Table (16), it is possible to say whenever the traffic number increases, the noise levels on the buildings facades increase. However it is seen that this increase vary from one urban form to another, some vary around 1dB (A) and others around 1.5dB (A), and this variation depends on buildings implementation in each urban form.

In order to find a relation between the urban indicators and the traffic variation, the study presents the results of the urban indicators for the chosen urban forms, the corresponding average noise levels generated from the variation in the number of vehicles scenarios - the results of the scenario 300 vehicles/h was previously presented to assess a previous analysis-, their graphs and trend lines.

The results of the occupation index (P%) for the eight urban forms, the corresponding average noise levels generated from the previously described procedure, their graphs and trend lines are presented in Figures (5.29 and 5.30).

Forms	Leq dB(A)	P (%)
1	53.7	30.4
2	51.7	36.9
3	49.5	25.1
4	51.3	29.1
5	51.6	20.2
6	48.7	23.0
7	49.6	36.2
8	55.9	16.9

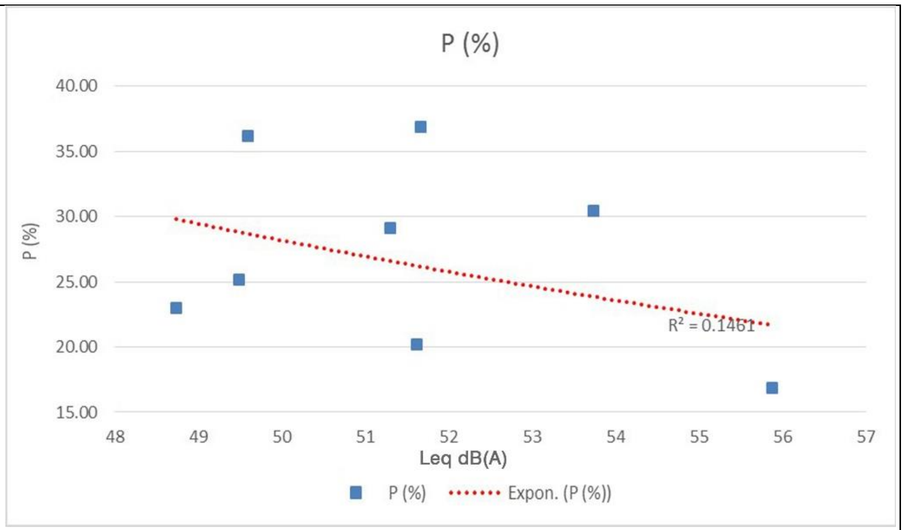


Figure 5.30 Illustration of the relationship between the occupation index and the average noise level Traffic number scenario 200 vehicles/h

Forms	Leq dB(A)	P (%)
1	56.7	30.4
2	54.7	36.9
3	52.0	25.1
4	52.9	29.1
5	54.6	20.2
6	51.7	23.0
7	52.1	36.2
8	58.4	16.9

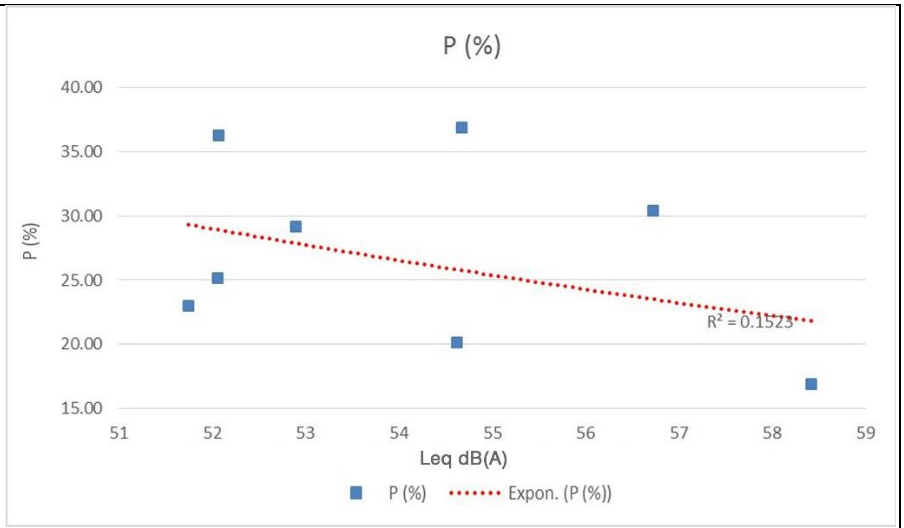


Figure 5.31 Illustration of the relationship between the occupation index and the average noise level Traffic number scenario 400 vehicles/h

Figures (5.31 and 5.32) present the results of the volumetric index (IV), the corresponding average noise levels generated from the traffic number variation scenarios (200 vehicles/h and 400 vehicles/h), their graphs and trend lines.

Forms	Leq dB(A)	IV $(m^3)\times 10^{-3}$
1	53.7	136119.8
2	51.7	165146.5
3	49.5	112501.8
4	51.3	130368.0
5	51.6	90272.0
6	48.7	102854.1
7	49.6	162139.5
8	55.9	75600.0

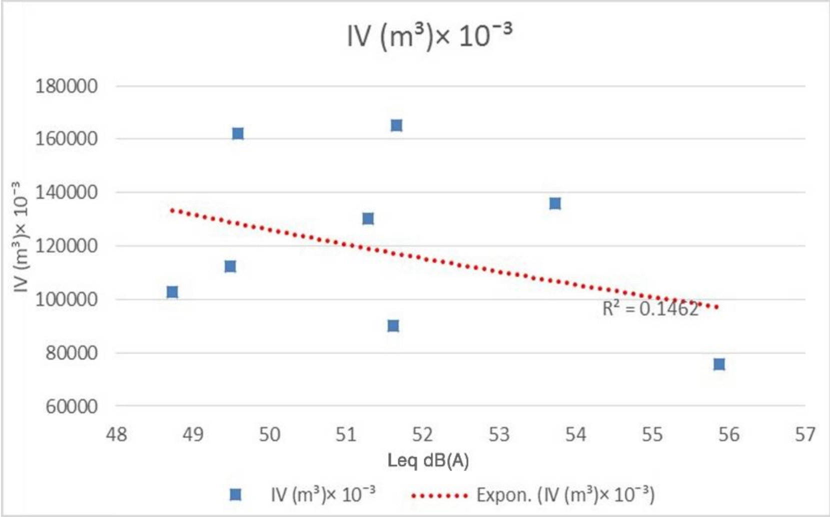


Figure 5.32 Illustration of the relationship between the volumetric index and the average noise level
Traffic number scenario 200 vehicles/h

Forms	Leq dB(A)	IV $(m^3)\times 10^{-3}$
1	56.7	136119.8
2	54.7	165146.5
3	52.0	112501.8
4	52.9	130368.0
5	54.6	90272.0
6	51.7	102854.1
7	52.1	162139.5
8	58.4	75600.0

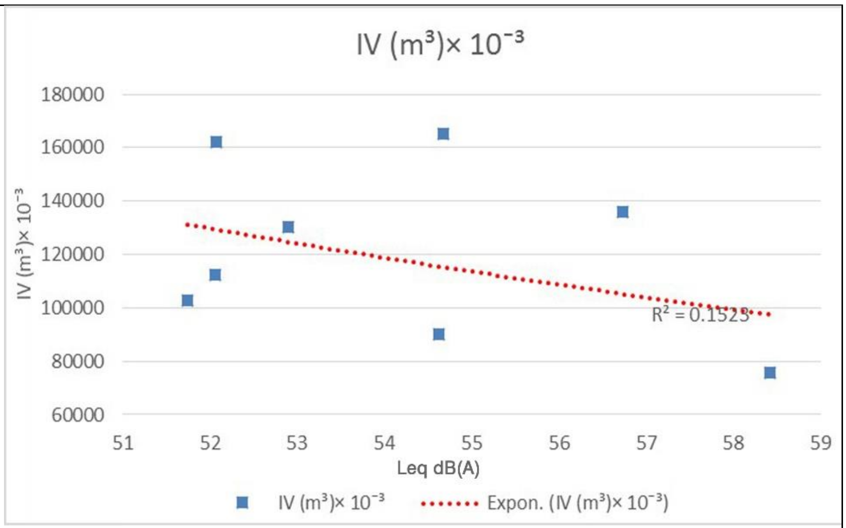


Figure 5.33 Illustration of the relationship between the volumetric index and the average noise level
Traffic number scenario 400 vehicles/h

The results of the porosity index (ROS) for the eight urban forms, the corresponding average noise levels generated from the scenarios of the variation in the number of vehicles, their graphs and trend lines presented in Figures (5.33 and 5.34).

Forms	Leq dB(A)	ROS (%)
1	53.7	69.6
2	51.7	63.1
3	49.5	74.9
4	51.3	70.9
5	51.6	79.8
6	48.7	77.0
7	49.6	63.8
8	55.9	83.1

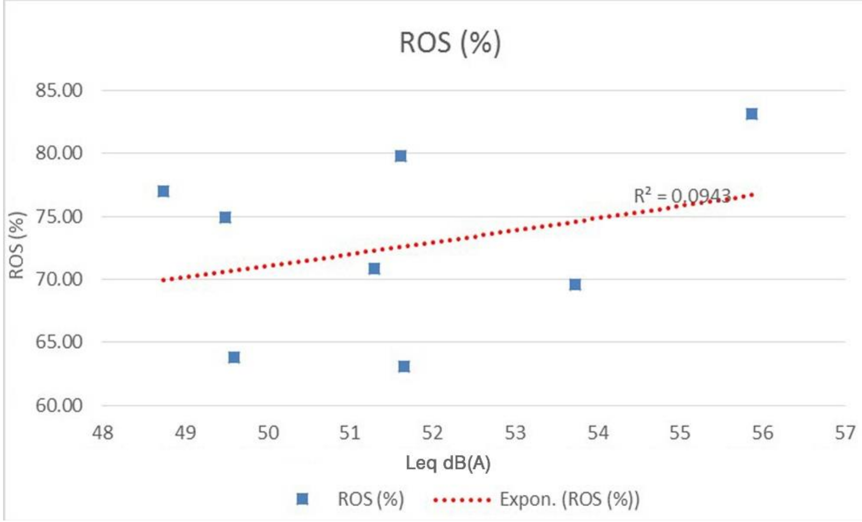


Figure 5.34 Illustration of the relationship between the porosity index and the average noise level Traffic number scenario 200 vehicles/h

Forms	Leq dB(A)	ROS (%)
1	56.7	69.6
2	54.7	63.1
3	52.0	74.9
4	52.9	70.9
5	54.6	79.8
6	51.7	77.0
7	52.1	63.8
8	58.4	83.1

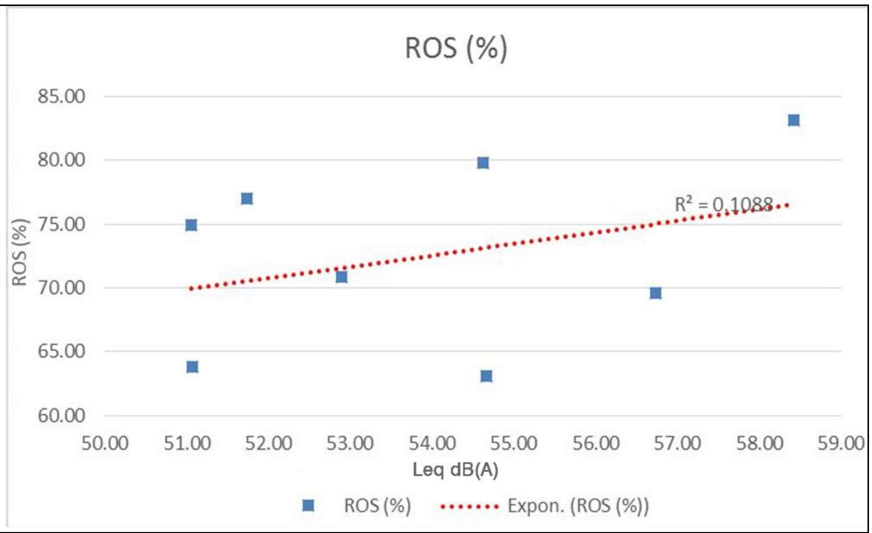


Figure 5.35 Illustration of the relationship between the porosity index and the average noise level Traffic number scenario 400 vehicles/h

Figures (5.35 and 5.36) present the results of the compactness index (CI), the corresponding average noise levels generated from traffic number variation scenarios (200 vehicles/h and 400 vehicles/h), their graphs and trend lines.

Forms	Leq dB(A)	CI (-)
1	53.7	0.56
2	51.7	0.73
3	49.5	0.86
4	51.3	0.77
5	51.6	0.82
6	48.7	0.77
7	49.6	0.72
8	55.9	0.75

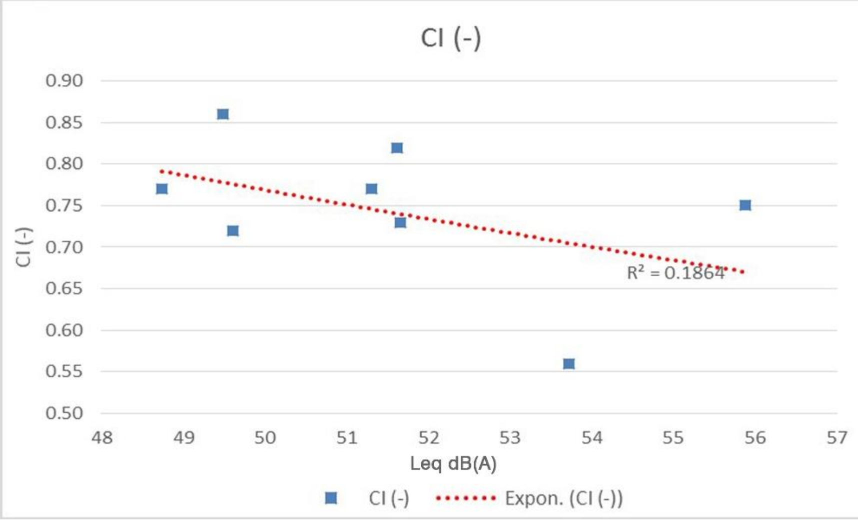


Figure 5.36 Illustration of the relationship between the compactness index and the average noise level
Traffic number scenario 200 vehicles/h

Forms	Leq dB(A)	CI (-)
1	56.7	0.56
2	54.7	0.73
3	52.0	0.86
4	52.9	0.77
5	54.6	0.82
6	51.7	0.77
7	52.1	0.72
8	58.4	0.75

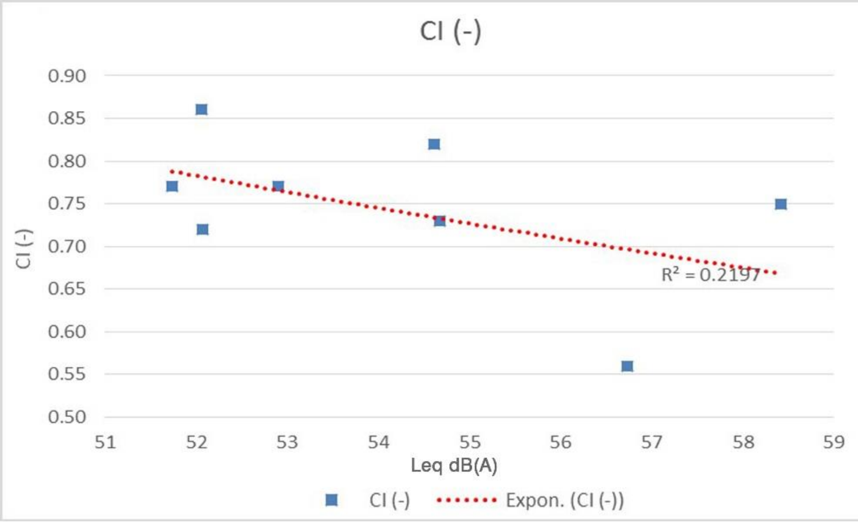
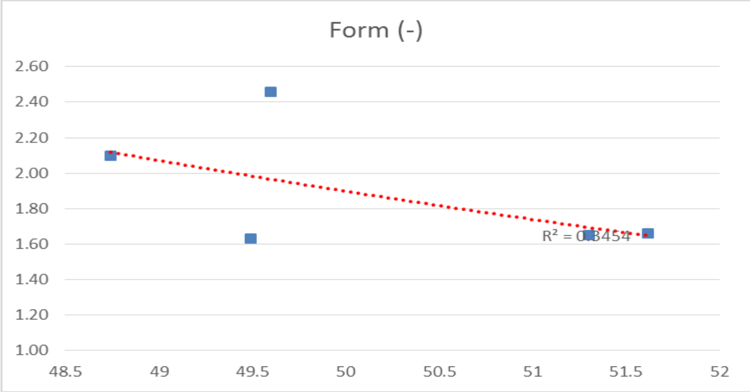


Figure 5.37 Illustration of the relationship between the compactness index and the average noise level
Traffic number scenario 400 vehicles/h

Figures (5.37 and 5.38) present the results of the form index (Form) for the previous two divided groups of urban forms, the corresponding average noise levels generated from the scenarios of the variation in the number of vehicles, their graphs and trend lines.

1st Group Forms	Leq dB(A)	Form (-)
3	49.5	1.63
4	51.3	1.65
5	51.6	1.66
6	48.7	2.1
7	49.6	2.46



2nd group Forms	Leq dB(A)	Form (-)
2	51.7	2.81
3	49.5	1.63
4	51.3	1.65
5	51.6	1.66
8	55.9	2.26

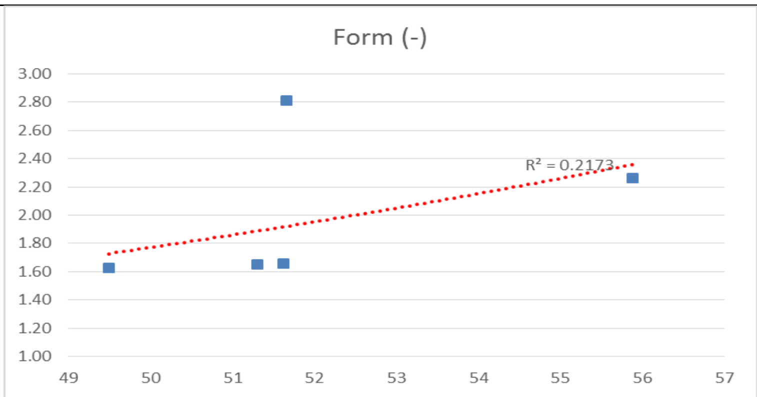
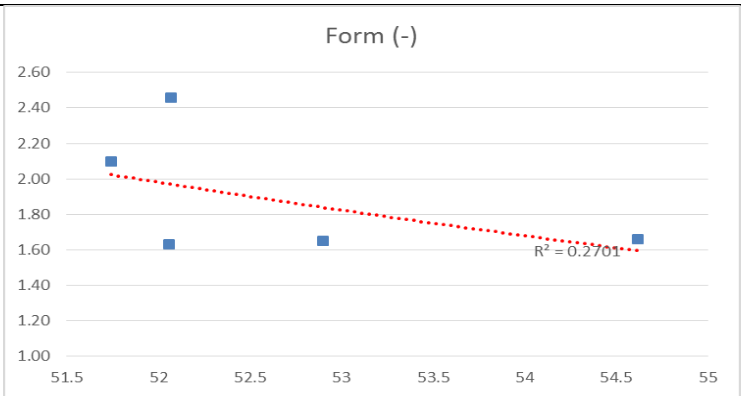


Figure 5.38 Illustration of the relationship between the form index and the average noise level
Traffic number scenario 200 vehicles/h

1st Group Forms	Leq dB(A)	Form (-)
3	52.1	1.63
4	52.9	1.65
5	54.6	1.66
6	51.7	2.1
7	52.1	2.46



2nd group Forms	Leq dB(A)	Form (-)
2	54.7	2.81
3	52.1	1.63
4	52.9	1.65
5	54.6	1.66
8	58.4	2.26

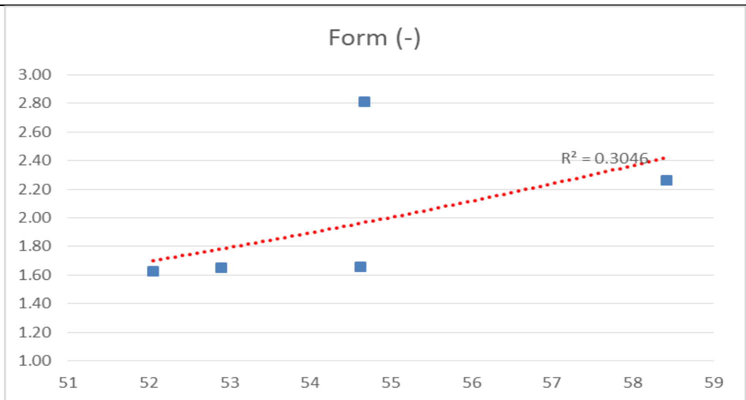


Figure 5.39 Illustration of the relationship between the form index and the average noise level
Traffic number scenario 400 vehicles/h

From the previous figures which aimed to find a relationship between the urban indicators and the scenarios of the variation in the number of vehicles, it is noticed that a variation occurred in R^2 when the number of vehicles varies. It is found that with the increase of the number of vehicles the R^2 increases, which means that the relationship between noise levels on buildings facades and urban form indicators is higher when the number of vehicles increases.

5.5 The influence of access roads on noise propagation

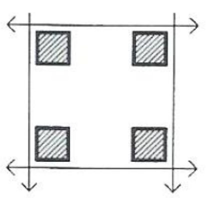
The access roads are the roads that are used to access the parking lots, and more roads mean more noise. It was not possible to take into consideration the noise emissions which are generated from the access roads and the local roads in the development of the previous analyses, because each urban form has a different type of road access, a different number of access roads, and a different number of local roads.

However, this study is going to present the influence of these access roads on noise exposure levels on buildings facades for the eight urban form, in order to understand this influence.

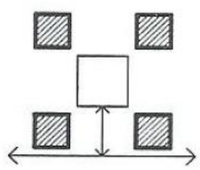
The developed scenarios to assess this analysis have the following characteristics:

- The main roads:
  - Number of vehicles: 300 vehicles/h.
  - Speed of vehicle: 50 Km/h.
  - Road surface: Smooth asphalt.
  - Road gradient: 0%.
  - Road traffic flow: Continues fluid.
- The local roads:
  - Number of vehicles: 20 vehicles/h.
  - Speed of vehicle: 40 Km/h.
  - Road surface: Smooth asphalt.
  - Road gradient: 0%.
  - Road traffic flow: Continues fluid.
- The access roads:
  - Number of vehicles: 5 vehicles/h.
  - Speed of vehicle: 15 Km/h.
  - Road surface: Smooth asphalt.
  - Road gradient: 0%.
  - Road traffic flow: Continues fluid.
  - Type of roads access:

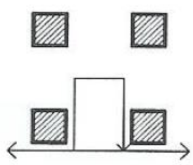
Continues access



Square access



Ring access



Dead-lock access

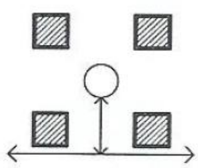
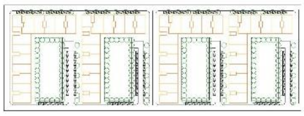
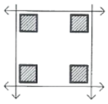
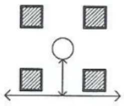
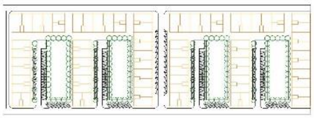
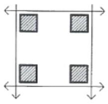
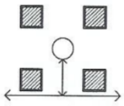
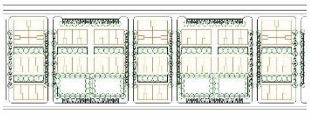
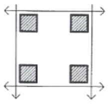
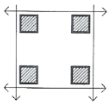
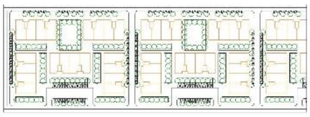
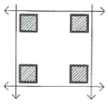
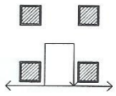
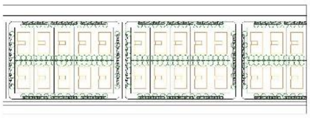
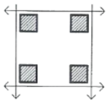
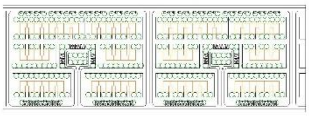
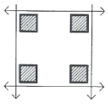
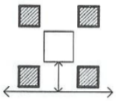
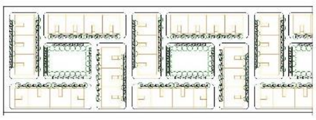
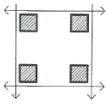
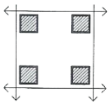
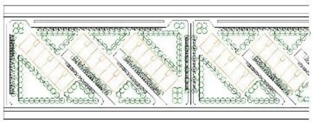
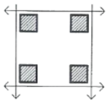
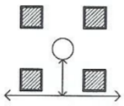


Table 17 The influence of access roads in the noise levels

Forms		Local roads		Access roads		Leq dB(A) without access roads	Leq* dB(A) with access roads	Leq* - Leq dB(A)
N°	**Type**	**Type**	**N°**	**Type**	**N°**			
1			3		4	55.5	56.3	0.8
2			2		4	53.5	54.6	1.09
3			3		3	51.2	54.0	2.75
4			3		2	51.7	52.5	0.85
5			3	——	0	53.4	53.6	0.27
6			3		2	50.5	52.2	1.69
7			3		4	51.4	55.0	3.68
8			2		3	56.8	57.0	0.24

From the results in Table (17), it is not possible to know which access road generates the less noise emissions, because of the variety of number of roads. Also because the influence of the noise emissions generated from the same type of road access on an urban form with high noise levels facades, is less than their influence on an urban form with less noise levels facades, as seen in urban form (1, 2, and 8) where the three of them have dead-lock access roads.

In addition, it is seen that the continued access roads generate the biggest difference between the average noise levels without access roads (Leq) and the average noise levels with access roads (Leq*), as seen in (urban form 3 and 7). Even though, this cannot be taken into consideration for the same previous reasons.

CHAPTER 6

6 CONCLUSIONS

The closed implementation form of a group of buildings is the best implementation in order to provide a noise-protected areas, because it prevents noise from entering inside the urban fabric, this type of implementation provides more noise protected area than the linear and punctuate implementation (for example urban form number seven).

If the implementation of buildings were linear or punctuate, it is better to do the buildings implementation parallel with the roads (to the noise source), to maximize the possibility of providing noise-protected areas by using the buildings mass properties. In these cases of implementation if the buildings were perpendicular to the roads, the possibility of creating noise-protected areas by using the buildings physical properties decreases, and other obstacles should be used to reduce the noise-exposed levels of buildings facades.

When there are openings between the buildings, it is better to do these openings on the perpendicular side of the urban form in relation to the noise sources, so the increase of noise levels will be minimal. Also, when the openings have to exist on both perpendicular and parallel sides of the urban form in relation to the line of the noise sources, it is better to do small openings on the parallel side and bigger ones on the perpendicular side.

One of the effective ways to reduce noise is to enlarge the distance between the source and the receiver. It is seen from the third form in Figure (6.1), the distance between the road and the facade of the second building reduce (6 dB (A)) from its level on the facade of the first building.

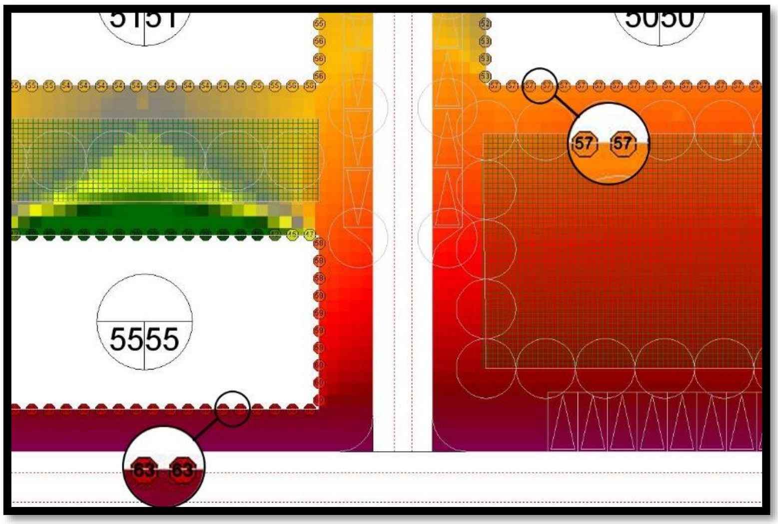


Figure 6.1 Illustration of the influence of the distance on noise levels in the third form

The increase of the occupation area, increases the existence of obstacles, maximize the possibility to create noise-protected areas, and minimize the noise that enters into the urban fabric. Thus, when the occupation index (P%) and the volumetric index (IV) increase the noise levels decrease, and when the porosity index (ROS) increases the noise levels increase.

When the buildings positions and their implementation in relation to the roads provide noise-protected areas, then longer buildings lead to less noise on facades. In this case, when the form index (Form) increases the noise levels decrease. But if the buildings positions and their implementation in relation to the roads do not provide noise-protected areas, then longer buildings leads to higher noise levels on facades. In this case, when the form index (Form) increases the noise levels decrease.

The relationship between noise levels on buildings facades and urban form indicators is higher when the number of vehicles increases. If so, the noise emissions from these roads increase, and consequently the noise levels. As well, the same relationship is higher when the speed of vehicles increases, thus the noise levels increase.

It is better to put the parking lots underground or around the urban form to prevent the access roads from being inside the urban fabric, and the generated noise emissions from these access roads.

The use of noise prediction method 'NMPB 2008' and the CadnaA software in this study, allowed the creation of several scenarios and the prediction of the noise levels generated from these scenarios at the design stage. It allowed to know which scenarios of urban form provide facades that exposed to high noise levels and which scenarios provide facades that exposed to low noise levels, in this way, it was possible to minimize the effects of noise on facades in advance, by using the properties of the buildings mass, the locations of buildings, and the configuration of the built urban form.

6.1 Recommendations

1. Exploit the natural potential of reducing noise such as wind, topography, and vegetation.
2. Forming and designing buildings in order to reduce the exposure of noise, and using sound-absorbing materials on the facades.
3. Provide and improve public transportation, in order to reduce the usage of individual vehicles, which will reduce noise.
4. Encouraging pedestrian movement and the use of bicycles, by improving the pedestrian paths and creating lanes for bicycles, in order to reduce the usage of vehicles.
5. Separating between the sensitive activities to noise (such as residential areas, cultural centers, and schools), and the highways by using non-noise sensitive areas such as recreational areas, commercial areas, and open areas as a buffer zone between them.
6. Determine and reduce the speed limits, especially in the sensitive areas to noise.
7. Excluding the non-compliant activities with a residential function from residential areas, in order to reduce roads traffic in residential areas.
8. Placing the industrial areas outside the cities, would reduce the high noise emissions generated from them.
9. Establishing highways outside the cities in order to prevent the travelers' vehicles and heavy trucks from using the local roads inside the cities.

6.2 Suggestions for future work

Future studies could provide continuance simulations of the relationship between urban form and urban noise, providing more scenarios such as using sustainable materials for the roads surface, the sidewalk covers, and the buildings facades.

Future works could expand from studying the noise impact on the buildings facades to analyze the noise transmission from the exterior facades to the interior components of the buildings, using several scenarios of facades materials.

Developing the CadnaA software by adding factors that have effects on noise propagation such as; adding more land cover (soil, sand, and grass) and their absorption characteristic; adding trees library (type of trees, height variation, and their absorption characteristic); and adding weather conditions properties such as (temperature, humidity, and wind direction and velocity). Adding these factors will provide more realistic results for future studies in the acoustic field.

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