Solving New Noise Problems in Smart Cities

Final Report

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Abstract

The quickly changing scope of cities is expected to introduce new issues that will magnify the problem of noise, which is already considered to be the second biggest environmental cause of health problems. The purpose of this project carried out under European Project Semester at International Faculty of Engineering of Lodz University of Technology was to research the scale and consequences of noise pollution, the topic of smart cities and noise problems they might present and to try come up with ideas to help mitigate these problems. Previous studies have shown that about 20% of European citizens are exposed to unhealthy noise levels, which might contribute to numerous health issues and a dozen of thousands of premature deaths every year. What has been also observed is that member states of the European Union do very little to fight with this problem. During this project, our team consisting of: Arne Dylst, Krzysztof Kubiak, Daniel Puerta and Josep Maria Salvó conducted a deep research on how we imagine future smart cities will look like and how some European countries have approached this subject so far. Through numerical modelling and experiments in a Lodz University of Technology's anechoic chamber, we also investigated theory of sound propagation and acoustic properties of different materials. Moreover, using Fast Fourier Transform, we examined the spectrum of sound generated by an octocopter drone. After analysing all obtained results, we concluded the project with three ideas on how the problems of drone-caused noise and noise pollution in general might be fought in the future, first of which was to consider creating buildings with angled facades. The second idea was to put more focus on soundproofing more constructional elements of a building, such as floors, and the last one elaborates on a promising acoustic property of solar panels, which might be of help with absorbing drone-generated noise.

Introduction

The pace at which humans develop the world has been observed to be constantly increasing. According to "The Law of Accelerating Returns", various evolutionary systems' rates of change have a tendency to increase exponentially (Ray Kurzweil, 1999) and the development of technology has seemed to coincide with that theory. New technologies are being developed faster and faster, and the time until ground-breaking technologies are used by the public mass decreases at, what seems like, an exponential pace.

This contributes to the rate of advancement of a variety of areas of our everyday lives and one of the ways it has manifested itself is an ongoing smart revolution. Phones have turned into smartphones, TV's have turned into smart TV's and a similar process has reached cities, which are home to over 56% of world's population (U.N. Population Division, 2018).

Similar to how technological devices become smart, cities are being developed in order to advance efficiency, comfort, and safety of their inhabitants, which means an appearance of new features and advancements of existing ones. However, we must not forget, that everything comes with its disadvantages, which also applies to urban lifestyle.

People living in contemporary cities have to deal with numerous problems, which affect their lives in a significant way. Issues like traffic impact how efficiently and comfortably we live and work, however there are ones, such as air or noise pollution, which drastically influence our health and the longer we fail to mitigate them, the more lives will be negatively affected.

During the summer semester of 2020/2021 academic year, our group has participated in the European Project Semester program in Lodz University of Technology, under the topic "Solving New Noise Problems in Smart Cities" and focused on the issue of noise pollution in future smart cities. The goal of this report is to present how we worked on the project, what we did and what our ideas for contribution to fighting the problem of noise in smart cities are.

The following chapters of this report will cover all main stages of our work throughout the semester.

In the first chapter, we will focus the first and the shortest phase, which was focused on our team. We will introduce ourselves as team members and describe how we decided to organise how we worked further on the topic of our project.

In the second chapter, we are going to describe the phase of theoretical research and brainstorming. First of all, we will go through what we explored in the topic of smart cities and what our imaginations of future smart cities are. Then, we will cover the observations and predictions of how our resident countries have and might approach the smart transition and lastly, we fill focus on the data we have on the noise pollution, its effect on human health and what noise problems people might face in future smart cities.

In the third chapter, we will cover the experimental part of our project. We will cover the measurements and calculations we performed during this phase, our motivation behind them, their course, results, and our conclusions.

In the fourth chapter, we will describe the project's final stage, which concerned processing of the outcomes of all our activities and formulating our ideas for how the problem of noise pollution could be handled in future smart cities.

Project timetable

In order to allow a quick and easy visualization of what we did and in what order during this project, we prepared a simple Gantt chart of activities we performed presented in the following figure.

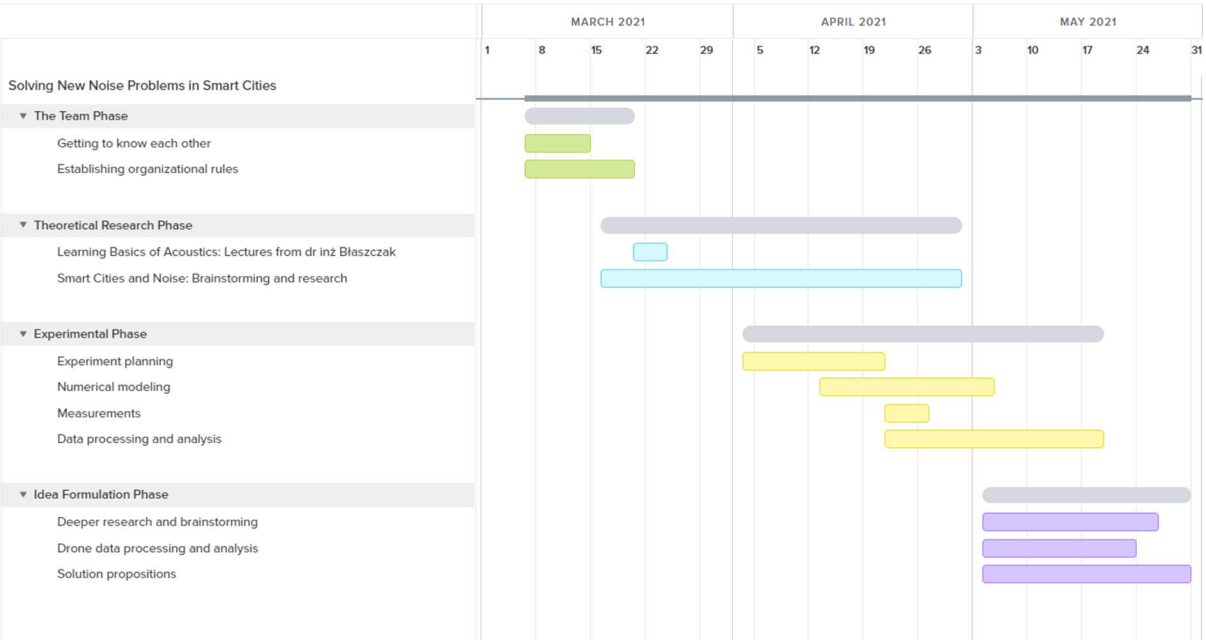

Fig. 1 Project Gantt chart

In the chart, there four categories of activities can be distinguished, each corresponding to a main phase of our project.

The first and the shortest phase of the project was the team phase, during which we got to know each other and developed a set of organisational rules for how we worked later throughout the semester.

During the second phase we focused strictly on gaining as much necessary knowledge as necessary. Our mentor, dr inż. Błaszczak, was kind to give us a couple of lectures on basic theory of sound propagation. Meanwhile, all of us were conducting deep research on the topic of smart cities and noise pollution.

In the process of theoretical research, we launched a second, concurrent stage of the project, the experimental phase. What we did during that phase, was conducting an experiment in an anechoic chamber, numerical modelling of sound propagation and the analysis of achieved results.

Towards the end of that analysis, we were able to begin the last part of the project, which was the idea formulation phase. It was the time, during which we processed the data we had gathered and researched remaining information, which were necessary to formulate our ideas concluding the project.

1. The team

The first stage of every project is to become acquainted with the people one is going to work with and organize how they are going to work as a team. Hence, as soon as we realized who we will work with on the project, we started getting to know each other. With help of exercises during Team Building and Communication for Projects classes, we shared our interests, project experience, strengths and weaknesses, meanwhile setting ground rules for the team for the whole semester.

In this chapter we are going to cover our team members, which we decided to call "The Noise Boys", how we decided to organize us working together and the schedule of what we did regarding the project throughout the semester.

Fig. 2 Noise Boys logo

1.1 The Noise Boys

Krzysztof Kubiak

Fig. 3 Krzysztof Kubiak

Krzysztof is 22 years old and comes from Sieradz, a small Polish city in the centre of the country.

He studies his 6th semester of bachelor level Computer Science studies at International Faculty of Engineering of Lodz University of Technology. During his studies, Krzysztof worked on numerous team projects, both strictly IT and interdisciplinary.

Josep Maria Salvó

Fig. 4 Josep Maria Salvó

Josep Maria Salvó Carmona comes directly from a small village called El Vendrell in the northeast of Spain, in Catalonia's region. Just to put you in some cultural context, in that region Catalan is the main language, and he grew up surrounded by sea on the east and small mountains on the west.

He has studied mechanical engineering at Polytechnical University of Catalonia, and this is his last year. During the studies he worked on many projects, like designing the installation and evaluation of hydraulic and thermal systems, as well as some projects related to electric power supply and material science.

Even so, he ended up specializing in the branch of industrial calculus and machine design, since he believes it is there where he can put all his ideas into practice and create something useful – while he is also having some fun. His goal is to put all his knowledge and effort into creating machines that help people to have the minimum welfare covered.

Arne Dylst

Fig. 5 Arne Dylst

Arne grew up in the city Antwerp in Belgium. It is in Flanders, the northern part of Belgium. The people there speak the Dutch language.

Arne studies electromechanical engineering in Antwerp and is currently in his last year and finishing his degree. During his studies he has specialized in maintenance.

Daniel Puerta

Fig. 6 Daniel Puerta

Daniel is 22 years old and is also from Spain, in this case, Daniel was born in the south-east of Spain in a small village called Cehegín (Murcia).

He is currently studying electronics and automatics engineering in the Polytechnic University of Valencia. Currently in his last year of the degree in which he has learned mainly power electronics, analogy electronics and digital electronics. Also, he has learned skills like automatics, robotics programming, PLC language and electrical installations. He is keen on new technologies, renewable energies and has futuristics point of view on how the world will be changing in the following years.

1.2 Team organization

The current state of the world forced many universities, including Lodz University of Technology, to transition to remote learning. It significantly influenced the way we worked on the project, which is why one of the main organizational issues to address was to choose the tools, which would allow us to collaboratively work remotely and be as efficient as possible in such situation.

Our choice for meeting within the group or to consult with our mentor was Microsoft Teams, as it was the main program used to conduct classes, which is why everyone had been familiar with it from the start. We decided to conduct meetings twice a week with dr inż. Błaszczak, and meet additionally when such need arose.

When we needed to prepare presentations, such as Ignite or Mid-Term, Google Slides proved useful as it offered us a significant number of useful features similar to the ones found in PowerPoint, but bested Microsoft's online services by allowing us to work seamlessly at the same time without noticing any performance issues.

In order to keep track of our progress, manage tasks and resources, we decided to create a board on Trello, where we would keep a list of tasks to be done, done or in progress and links to our presentations, files, and resources.

As far as roles of particular members in a team, we deliberately decided not to assign any in order not to limit our capabilities. We realized that each teammate has different strengths and weaknesses, however each member has a variety of skills, which could have proven useful in many aspects of the project. Not defining the roles let us provide equality in the team and made dynamic task allocation easier, which we decided were the most important for us.

2. Smart Cities

Since the topic of our project strictly focuses on smart cities, one of the bigger steps throughout the semester was to deeply study this subject in order for our work to be as accurate as possible. In this section, we are going to detail the research we did on smart cities and how each member of our team imagines such city is going to look like.

2.1 What are smart cities?

Curiosity has always been an important part of human nature and has been the force that drove us to develop and innovate, but also wonder about our future. Inability to predict coming times with absolute certainty has not stopped us from thinking about how the future of transport, work or communication will look like.

An enormous part of a person's lifestyle is defined by the environment they live in. Over a half of world's population lives in cities, which is why the future of cities is an important and interesting topic. Based on recent trends in various fields of technology, we think it is safe to say that cities in the future will become smart.

However, in order to understand what it means, we had to take a closer look at the concept.

2.1.1 Context and history

Smart cities are defined by the European Union as "a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business" (European Commission, n.d.). A definition that matches our most comfortable vision of the definition of *smart*. With the use of this information, we hope that it aims to create a smarter urban transport, to help to create the infrastructure needed to deliver water supply, to organize the waste that will be generated, to create more and safer public spaces, and more interactive and response city administration, that can meet the needs of all the inhabitants.

Truth being said, this digital revolution of thinking about the cities, what some experts called "the 4th one" has already started. Most cities of the world in the last years have been subject to mass transformation of numerous existing services into digitality or emergence of new ones, like the transportation and delivery service companies such as Uber, Bolt or Glovo. Companies that, through a digital method, provide features, which before were only meant to be done by analogous means.

This massive revolution induced a rapid digitalisation of nearly every part of our modern lives. In November 2017, Google installed digital devices all over New York, called Links, with the expectation that, in the future, they will serve as infrastructural nodes through all the information will be connected -like the ones of smart carts, urban transit and other public services data (Mattern, 2017). Also, they installed in 2015 Wi-Fi points in basic places like kiosks and have been recently launching subdivisions to investigate in the same branch that we are doing with this project: smart cities.

After all, it seems noticeably clear that the cities are turning into a digital and self-regulated direction: In the imaginative plan to understand cities as computers, with us, humans, generating the data, it seems logical that they also need to evolve and become smart, a metaphor that is easy to generate in the smart era, where we want everything organized and on time. But is it true that cities need to become smart? If so, what have the cities been all this time? We decided to research and analyse deeper.

We believe that cities, since the very beginning, have been fundamentally communicative and connective, spaces rich in information that was gathered through the public administration and served as a purpose to keep a certain form of organization. As an illustration of this, we can see how even the first written document that we have evidence of, was a clay tablet, where the amounts of goods of the big city of Uruk (Harford, 2017), a Mesopotamic city and one of the first in the world. In history's very first cities, there were already some forms of organization, an attempt to keep the track of the information that was relevant in order to improve the welfare of the inhabitants.

Relative to how long the history of humankind is, a fairly recent revolution happened in Italy in the mid-16th century. There, Uffizi Gallery was created, and it was the key into settling a standard that was replicated among all the powers in the world and even nowadays. Although nowadays it is one of the best art museums in the world, back in its epoque, it served as way to gather all the administrative offices (it. *Uffizi* "offices") under one roof, forming one of first bureaucratic departments that we have proof of (Uffizi Gallery Museum). Those offices also did the same purpose of gathering information about the city in order to establish the economic and social directions most beneficial for the city. And since then, we have been following more or less the same guidelines.

2.1.2 What is urban intelligence?

Altogether, we have seen that the cities are already serving as a space to organize the life of its inhabitants and to establish regulations based on the data generated by them and business companies. We could consider that they already are smart cities, the only change from nowadays would be the form of how they gather and distribute the data and distribute it through diverse mediums, both analogous and digitals, as well as the services and infrastructures that can be automated.

Nevertheless, we should also focus on the data which cannot be stored, because they constitute a big source of knowledge and information that need to be prevailed in order to set a successful future for the city, since we firmly believe that, even though all the future cities will look alike, there will always be some kind of difference due to this cultural data.

The truth is that urban intelligence is generated in numerous forms, all of them produced by environmental and cultural context, that remind us to not consider the future cities only in a "logical" scope but as well in a climatic, geological, sociological way. Still, there are limitations on what kind of information we can process: dancing, tradition, the local effects of the weather in a population, how gentrification affects some neighbours and what effects it has on the people, etc. All these things are still urban intelligence that need to be understood.

As we see, urban intelligence also involves site-based experience and active participation of its inhabitants, and we should think about models that can store this information and make it prevail, thereby reinforcing the human dimension of the future inhabitants and political systems that may rule. Instead of focusing only on the digital part of numbers and pure data, there is a need to look for this kind of data in context, not in abstract, to open a way so the future cities can recognize the memory and history existent in citizens, acknowledge the information generated by them and act in the best way possible taking into account both digital data and cultural data, or, considering them as one, urban intelligence.

2.2 Our view of smart cities

A crucial step of our project was to define and understand how we imagine smart cities are going to look like. Each of us took their time and constructed a set of features they thought would define the smart features of a future city. That helped us create a collective set of components of a smart city, which we could focus on later while working on our project.

2.2.1 Individual thoughts

Krzysztof's view was that it does not require much for a city to become smart and that they will not change drastically, compared to how they look like now. He thinks that, besides a deeper integration of information technologies into various city components, the main changes would be the appearance of autonomous delivery drones and construction of high-speed tunnels, like the ones proposed by The Boring Company that would allow faster travel between distant parts of the city.

Josep Maria argues that smart cities will not really suffer a great transformation compared with nowadays ones. There will be changes that will gradually modify the way the communication is transmitted, probably by digital means. Eventually cities will need to find a way of communicate and process the data that will be encoded in the position of smart cars or in the devices that will store all the important information of their inhabitants, but, apart from that, the structures will be kept more or less the same. Nowadays there are a lot of companies working on that problem already and presenting big and important solutions.

In his view, the critical change in the cities will be not really their infrastructures but how they are organized. In cities in expansion, contemplating the problems derived from global warming and a more-than-probable migration from rural areas to cities, they will have to resolve how to keep offering the same services to an increasing population that will demand more and more.

In order to solve this, he believes that the cities will evolve into micro-cities inside the huge metropolis. Spaces where a population of half a million or a million people will be able to enjoy the same benefits as before but in a reduced area, having everything they want within 15-minute travel. Also, their inhabitants will need to learn how to coexist with the new technology that will surround them, like the futures delivery drones, help-assistant robots and so.

Arne thinks smart cities will not be too different from the big cities now. He thinks smart cities will all be about improving and incorporating new technologies, developing energy-efficient and ecological buildings, implementing ways for generating renewable energy inside the city and finally improving the transport through the city.

Daniel considers that smart cities are a very brand-new name in our contemporary society. It is the name for the next generation of cities that will appear in the next 20-50 years. However, these cities have many challenges among the optimization and reliability of these cities.

Due to the expected mobilization of the rural population into the big cities during the next decades, smart cities will be ready to increase their population density without decreasing the quality of live on it. The infrastructures of our cities will be different, higher buildings, including skyscrapers, including small gardens or forests in them to increase the ecological value of our city. Technology will be the nucleus of this project, everything will be controlled by technology, mostly IoT or Big Data which means that everything will be monitored and controlled by that.

We should forget the fossils fuels from our vocabulary, smart cities will be fuelled mostly by solar energy or other kinds of renewable fonts. Solar energy will be really important in this transformation due to the fact that is the most suitable font of energy for our smart city because we can integrate solar panels almost everywhere, even on windows or cars. Also, the offer and demand of solar energy will be developed by every user, not a unique enterprise owing that every small group of people (energy community) or single user will be able to buy or sell energy from their sources, allowing the free market economy.

Traffic will be also controlled by the digital systems which allows the city to be less chaotic and less noisy in certain periods of time. In fact, public transport will carry the most part of that traffic, it will become an important part of the structure in the life of the citizens. Also, we have to think in people transportation through the air either in drones or kind of helicopters or small planes, this will liberate a lot of traffic and space in the roads and streets our smart city.

There will definitely be more focus on integration of parks and natural spaces in the cities even than nowadays due to the impact of climate change and stability of natural course of our planet.

Finally, all of these innovative changes might introduce new problems that we don't expect.

2.2.2 Conclusions and collective view

Surprisingly, our imaginations of future cities appeared to be highly similar. Nevertheless, each team member had some individual ideas, which uniquely contributed to the final, collective view of a smart city, on which we would later base the rest of the project.

After combining all our concepts, we obtained a set of features we all believe that can define future smart cities. These set of 'rules' -if we want to call them- are in fact, more guidelines through what the future governments should consider when planning these big smart cities, places that will be in charge to provide welfare and a quality of life to almost all the world's population in the next 30-35 years.

To begin with, we all agreed that there will be an increase in the population due to migrations from warmer places and locations with a significant rise of sea level. Because of it, cities will have a need to locate all of these individuals. This boost of urban and population density will cause the formation of new and taller buildings. Immense skyscrapers will form the future of the city's landscape. Also, due to this big demand for space, it is very likely that the future smart cities will need all the surface possible in order to grow as much as possible.

We believe that these huge structures of buildings will be separated into 'spheres of life', being those spaces where a human being can have everything he desires/needs within 15-minute travel. Hospitals, schools, big green spaces and offices, among other basic spaces, will be located within a reasonable time-distance travel. Probably the skyscrapers will be organized in a way that allows some more recreational space in the bottom part, housing in the middle and workspaces in the very top. This, among other social platforms like stadiums, sport centres, supermarkets, etc, will create these 'spheres' acting as sub-cities where a considerable number of humans will live; all of them inside the same city but mostly unaware of what is happening in the rest of the city.

In a scenario, when we agree to this idea, the streets as we know must disappear. All the future transport will require a restructure from the very first concept of transport. Future inhabitants of smart cities will not have a real need to travel to distant locations. As globalization shrinks the world and makes it smaller, all the cultures will collapse in a more or less similar culture with no clear difference between one and another. That, along with the decrease of flights and fossil combustibles, will cause a stagnation of human communities, since there will be an almost-zero diversity between two antipodal points in the globe and the need for traveling and 'discovering' new places will be mitigated.

The future of transport lies in providing the necessary means so, if needed, people can move easily within the sphere they will be living in. In order to do that, because there will be a hefty amount of big green and recreational spaces wherever there are no tall buildings, we firmly argue that all the transport that has wheels will go underground. Just as metro, continuous lines of suburban highways will cover a considerable amount of the city underground. With so, this will not only help with the noise problem inherent to traffic but as well with expanding the city in a vertical space, both up with skyscrapers and down, releasing density-pressure on the overall.

If some form of transport still prevails on the top, that will be the drones that will perform as taxis (Shafranova, n.d.). In so much as they provide a very useful way to travel through space without any real constraints, it is a certainty that in the future they will be a constant in the sky. This, in addition to the delivery of packages and all kinds of services using drones, just like nowadays, will create an increase of these machines in the cities, generating a big noise problem to its inhabitants that will need to be resolved more soon than later.

We tightly realize that these colossal future smart cities will need an enormous amount of energy to operate; energy that unquestionably cannot come from fuel fossils and non-renewable combustibles. It is out of the scope of this work to come up with a solution for the energy problem that future generations will face - how can renewable energies provide enough power to keep all the electric cars moving, lighting all the residences and at the same time provide enough energy to keep the 'cloud' moving? After all these questions, we cannot help to think about some solutions that, even though they need a closer approach, we believe are worth considering.

Due to these energy problems, we assume that cities will take a major role in the production of sustainable energy that will help the major power plants to reach the energy level necessary. In order to help, we expect that the big cities will be covered in solar panels at the top. This, in addition to providing enough energy for sustaining the city, can help to mitigate the sound, as we will see in the next chapters. Additionally, we also imagine that in some buildings, small-scale windmills will appear, taking advantage of the fast winds that appear in the upper parts of a city.

2.3 Differences between countries

Another idea we had towards exploring the topic of smart cities was to take advantage of the fact we come from different countries. We decided to look into the approach our countries take to the subject and share our thoughts on how it looks like from our perspectives as those countries' citizens.

2.3.1 Poland

The development in Poland does not seem quite as rapid architecture-wise as one might imagine in a modern city. The bigger cities, where we might expect such fast development are usually old and mostly focus on revitalizing existing, older buildings.

These cities, however, have started to introduce some smart features. In most cities many of these features are associated with transport, like purchasing ecologic buses, building new and renovating old roads and creating modern municipal waste disposal plants. On top of that, local governments put an emphasis on increasing the efficiency of power, water and sewage infrastructures.

What is more, many cities, not only the biggest ones, try to expand the availability of public services and e-services, such as public bicycles, and improve the communication between the inhabitants and the government by introducing web applications and city lights to share information with or get feedback from them.

These smart changes in Polish cities seem to be triggered by a global drive for ecology and an Information Technology revolution, hence the ideas introduced so far are not limited to Poland or this region of the world and we cannot extract information from it which could indicate any features of Polish cities that differ from cities in other regions.

2.3.2 Belgium

In Belgium there are only a few regions subsidized by the government in terms of the smart city strategy. These are the following provinces Antwerp, West-Flanders and East-Flanders. In Antwerp the focus lies on smart transport and a high level of digitisation with for example the city of things project in Antwerp. There is also a big focus on green, quiet and sustainable transport with for example busses powered by electricity or hydrogen. The West -and East Flanders focus more on smart governance.

The biggest reason that Belgium is not supporting the smart city plans is because of the split governance in Belgium. Flanders is supporting these plans, but Wallonia and Brussels are opposing. This is a complicated situation found only in Belgium.

2.3.3 Spain

Spain has a very ancient history; many civilizations lived in those terrains. In fact, Spanish culture is based on the mix of all of civilizations that inhabited them. Therefore, most of the Spanish cities are really ancient with a lot of buildings and monuments that are protected by the government to keep the culture, which remind of what Spain had been through the years and attract tourist. It is a big reason why Spain is one of the most visited countries in the world every year.

The conversion of the Spanish cities to smart cities may be really challenging for the architects and engineers due to the fact of what has been mentioned before. However, starting from the ecological transition from fossils fuels to clean source of energy, it is much easier in Spain using photo-voltaic system because the sunny climate and the number of hours and intensity of that weather. Installing energetic communities in the big cities using solar panels will produce enough energy to supply the whole city storing not used energy or even to redistribute it due to the free market that will be applied owing the enormous number of communities that will work by themselves. Although solar energy is the easiest source of energy to install in the cities, there are other renewable energies that can be used like wind power or even hydraulic power in rivers. While trying to exploit these energy sources we have to think of the space and noise that they may produce, that makes them usable in the surroundings of the cities due to the fact that there will be enough space for them and the annoying noise that they may produce will not be an issue for the citizens and the overall amount of energy will be improve to even sell them into rural places or companies that will require it.

We chose Valencia to propose the architecture and infrastructure of the transformation to a smart city. Valencia is one of the most suitable cities to make the change to a smart city owing that it is a modern city with good climate and that it is continuously growing. Valencia has already one of the most futuristic building designs of Spain, which is the City of the Art and Science. We have decided to divide the city into four parts.

The first one would be the ancient part of Valencia, which will be conserved and revitalized to maintain the historical part of the city. Afterwards, the part of the city that surrounds the ancient part will be the target of this evolution, due to the fact that it is where most of the people live, work and travel through. Buildings will be redesigned to become part of the small energetic communities or to storage and use energy, the most suitable font of energy is the solar one due to the ease of implementation. These small communities could be distributed by districts, by small neighbourhoods or by buildings depending on their demands and needs.

Public transportation is already a big advantage in this city, there is an underground, enormous number of buses and trams to reach every single part of the city with a lot of stops nearby underground stations, trams or buses apart from the connections among them in some crowded stations. The only issue will be to reconstruct some parts of the underground and trams, change diesel buses to electrical buses and make a more efficient schedule for the passengers in all services, for example shorting the time of waiting in the main hours of the day (7-9 AM, 1:30-3:30 PM and 7-9 PM). To add something, there is a proposition to include bike rental service in many points of the city and electrical bikes rental service that anybody may leave and take in any place.

Another issue in this part of the city will be the continuous increasing of the population which means that buildings should be larger to be able to embrace all the demand of the population which may be used to redesign or rebuild the edifices into new trends or needs. Although we increase the amount of people that may live in this part of the city, if the population will be still growing and people from rural paces continuous to come to the city will be difficult to find a place to live, which means that the prizes of real estate in some districts will be higher and higher.

The third part of the city will be the touristic one, which is the districts that have the beach. This part will be even more connected to the other parts of the city due to the fact that it may be really crowded in some parts of the year, owing that, the beaches will be technologically developed but also, they will have a touristic point of view including hotels, restaurants, leisure places and touristic services.

The fourth part is the surroundings of the city in which all the industrial structures will be developed. This part is really important to the city due to the economic impact that it has. However, few cities have public transport to those places which is an issue to be included in the developing of the public transport. Although most of the workers could live in the city and go to the industrial estates to work, sometimes small communities or villages may be born nearby these industrial parks because they are much cheaper places to live and they save a lot of money in transportation. Also, such a part could embrace an energetic estate in which wind energy may take a part to supply the city and the industrial park as well.

To sum up, we have divided the city into four main parts: the ancient part, the nucleus of the city, the touristic part of the city and the surroundings. We have discussed about the energetic issues, architecture, transportation and tourism. We believe in the development of the city involving demographic efficiency, technological innovation and the conservation of historical buildings and monuments at the same time. Spain is a truly potential country in the development of the smart cities owing its environmental advantages, demographic situation and its power and technological companies that could reach that goal in the next generations.

2.3.4 Conclusions

Unsurprisingly, we observed a lot of similarities between these countries. Even though there are historical and cultural differences among how the cities were built and how they are managed, in the modern era, these differences slowly fade. The ideas in those countries for how to approach the smart evolution of cities are, in a significant part, the same. Digitalisation, introduction of new public services, a drive to be more and more ecological are all shared in all of the European Union and the world.

Similarly in the energetic field, differences in climates in different parts of the world may suggest the preferred ways of exploiting renewable energy sources, however all of them are used to some extent in every country.

There are a lot of similarities between these 3 countries. They are members of the European Union as well. Therefore, everyone will make the important change to the renewable energies in their cities, take care of their main cultural monuments and buildings without losing the focus on the transition in the city.

Transportation is also one common feature among the countries due to the fact that in the future smart public transportation, the most efficient way of travel in the city will be public transport.

To sum up, in the next decades, the cities will develop significantly in the ways we discussed. In Europe, this evolution is expected to happen at a similar pace thanks to EU regulations and what it allows in terms of a closer integration of member countries, however in the era of globalisation, similar changes are being observed and expected.

2.4 Noise problems

The next key step in the beginning of the project was to deeply research the topic of noise pollution to gather necessary knowledge and be able to define the problems we could focus on mitigating. In this chapter, we will focus on what has been observed by humans so far and our thoughts on how it might evolve in the future.

2.4.1 Why is noise a big problem?

Most people, even though they are aware of the issue of noise pollution, might not recognize its scale and the harm it may have on affected people. World Health Organization stated that they believe noise is the second largest environmental cause of health problems, being outclassed only by air pollution.

According to European Environment Agency's Report No. 22/2019 elaborating on Environmental noise in Europe (European Environment Agency, 2020), twenty percent of European citizens are exposed to unhealthy long-term noise levels, which corresponds to over 100 million people. It is also highly doubted that this situation will improve, as the report shows that policy objectives on noise stated in the Environmental Noise Directive of 2002 (European Commission, 2002) have not been accomplished.

What has been observed is that long-term exposure to high noise levels might cause various health problems, such as annoyance, sleep disturbance, negative impact on metabolic and cardiovascular systems or cognitive impairment in children. It is estimated that every year, noise contributes to 48 000 new cases of ischaemic heart disease and 12 000 premature deaths. On top of that, it is believed that "22 million people suffer chronic high annoyance, and 6.5 million people suffer chronic high sleep disturbance" (European Environment Agency, 2020). Another highly disturbing statistic is that 12.5 thousand school children suffer reading impairment in school due to aircraft noise.

This data, as troubling as it is, are only estimates because a high percentage of data is still missing. Many countries, cities or regions do not produce the noise maps required by the directive which makes it impossible to properly evaluate and address the issue of noise pollution.

2.4.2 Noise in smart cities

The pace of human development keeps increasing and it is certain that someday it will significantly change how the cities we live in look like. The increasing demand of mobility, addition of new noise sources will amplify the threat of noise pollution, which we are very slow to fight. Delivery drones or wind turbines will not only increase the sound density in the cities, but also widen the range of bothering us frequencies. On top of that, a rising population density, especially in cities, will only increase the number of affected people.

Therefore, people must raise awareness of this problem and quickly come up with solutions on how to mitigate its effects on people's health not only in Europe, but worldwide, as it is a global issue. During this project we took our approach at this area and tried to come up with how we can contribute to fight noise pollution.

3. The experiment

After we did some of that research and brainstorming, our first idea was to take huge advantage of access to an anechoic room at Lodz University of Technology and test a few objects made of different materials we believe will be crucial to a future smart city because they have to be reused somehow. In this chapter of the report, we will cover our motivation behind the choice of the materials, technical aspects of the measurements and their results.

3.1 Overview

The chamber we had an opportunity to make and experiment in was designed by our mentor throughout the project, dr inż. J.R. Błaszczak. Due to COVID-19 we were not able to meet at the University together, which is why each of us went to the laboratory separately, so we could all safely perform some measurements. We were not discouraged, however, because the idea behind the experiment was to measure acoustic properties of different materials and that way every member of the team could do the same measurements on a different object. Our motivation behind the idea was to explore whether some materials we feel are or could be crucial to a future smart city. We chose them from architectural and ecological standpoints.

Josep performed measurements on a wooden panel, because it is a natural material and is very common in many applications like furniture or in architecture.

Daniel’s session focused on a plastic panel, because we think that with the amount of plastic waste we generate, some new applications of recycled plastic would be appreciated to help with this problem.

Krzysztof did his experiment on a glazing package from a window because glass is becoming more and more commonly used, especially in modern cities where lots of new buildings are entirely covered with glass.

Finally, Arne performed measurements on a photo-voltaic panel, which is a highly useful object and would be great, if it could serve another good purpose if applied correctly.

Our goal during these measurements was to determine how these objects reflect and absorb sound. The results of this experiment could help us understand whether any of these materials could be used as a mean of fighting with noise pollution in a smart city.

3.2 Equipment used

3.2.1 Anechoic chamber

For our measurements we used the anechoic room located at Lodz University of Technology (Błaszczak, 2016). This anechoic room is unusual since there are no typical cones, pyramids or wedges. In the room there are flat and tilted walls made of rock-wool and stone-wool panels. This tilt helps to reflect the remaining sound upwards and to avoid acoustic standing waves.

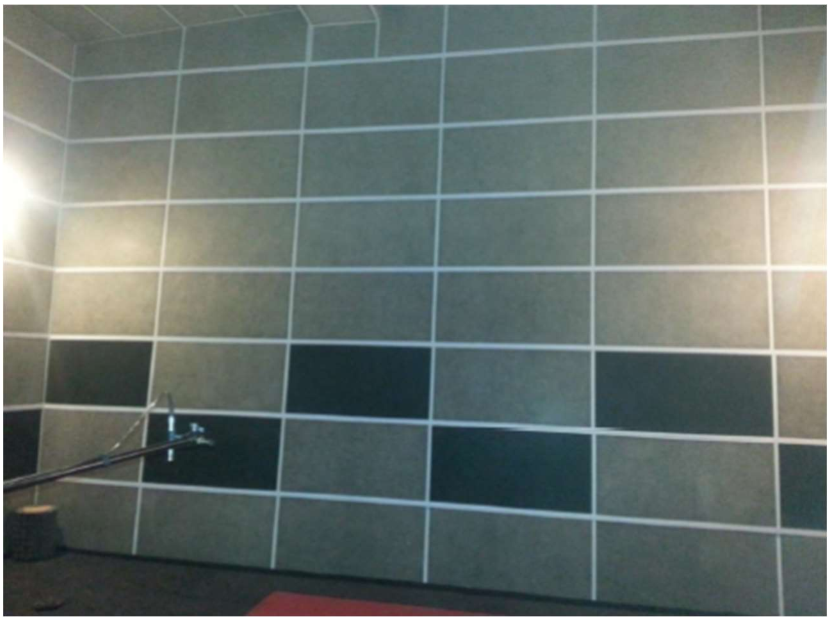

Fig. 7 - Inside of the anechoic chamber

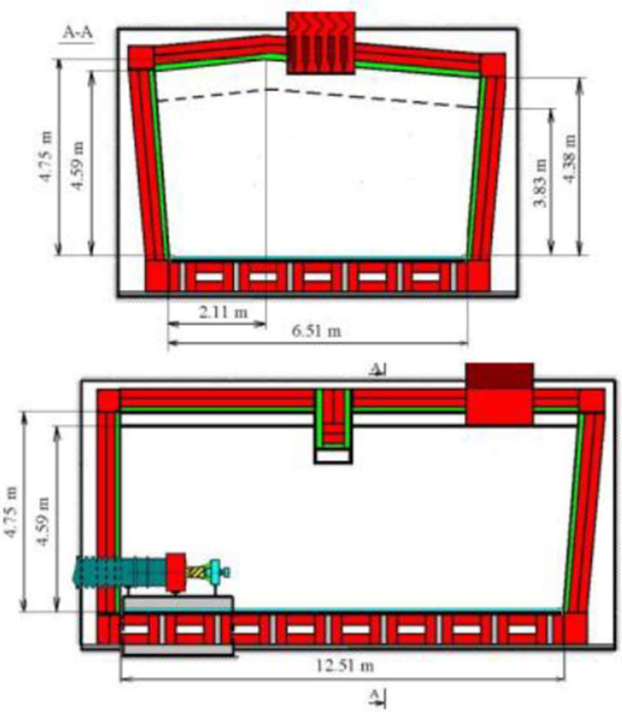

Fig. 8 Vertical cross-sections of the chamber (Błaszczak et al., 2005 and 2016)

There is also a vent present since this room is also used for aeroacoustics tests of turbomachinery and met the ISO 3745 and ISO 3746 standards, this is shown in the Article "New Aeroacoustics Facility at the Institute of Turbomachinery, Technical University of Lodz".

3.2.2 Microphone

For the measurements we used Brüel & Kjær 4189-A-021, 0.5 inch free-field-microphones with type 2671 preamplifier. This microphone is an acoustic transducer and it converts sound pressure fluctuations into electrical voltage variations. It has a sound pressure level range of 16.5 - 134dB, a frequency range of 20 – 20 000Hz and a sensitivity of 50mV/Pa.

Fig. 9 & 10 Brüel & Kjær 4189-A-021 microphone (Brüel & Kjær, n.d.)

3.2.3 Amplifier

For the measurements the Brüel & Kjær NEXUS SIGNAL CONDITIONER - TYPE 2693-A was used. This amplifier increases the voltage, current or power of a signal.

Fig. 11 Brüel & Kjær CCLD NEXUS SIGNAL CONDITIONER - TYPE 2693-A (Brüel & Kjær, n.d.)

3.2.4 Analog to digital signal converter and software

We used the converter WaveBook/516E. With this device we can transform the recorded analogue signals from the microphones to digital signals which can be used with the computer. The device works with software Wave View which is used for the sound recording on the computer.

Fig. 12 WaveBook/516E converter (Measurement Computing Corporation, n.d.)

3.3 Setup

The setup was a three-channel acoustic measurement system equipped with three free-field microphones with preamplifiers. Connected to three-channel signal amplifier and finally to an analogue-to-digital converter. The configuration was controlled by a remote computer outside of the anechoic room.

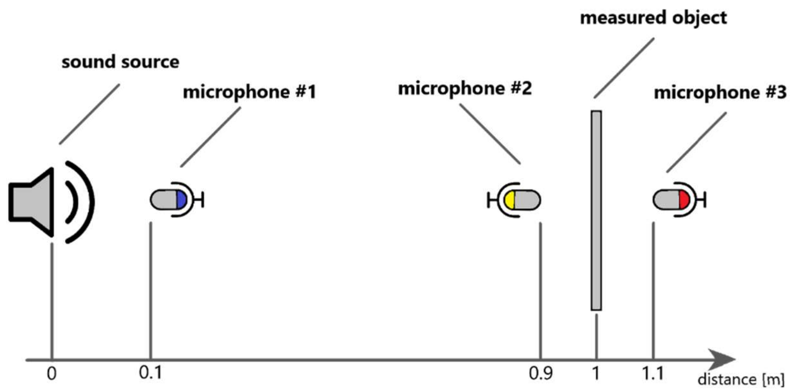

Fig. 13 Measurement setup's schematic diagram

Fig. 14 Photo of the measurement setup from the session with a glass window

According to the standards every measured object was located 1 meter from the sound source with the microphones 10 centimetres from it in both sides. As shown in the schematic in the figure above (Fig. 13), microphone #1 measured the sound intensity of the sound source, microphone #2 measured the reflected sound from the object and finally the microphone #3 measured the sound transmitted through the object.

3.4 Measurements

During the experiment we started by measuring the background noise without the sound source. We do this to verify if the test was valid, because the difference between the noise sample and the background must be bigger than 6dB, according to the ISO standards.

Next, we jumped up an octave; this means that our next measurement was on 16 Hz, then 31.5 Hz, 63 Hz, 125 Hz... till 8000 Hz. We hoped to determine how well the materials let the sound pass through and reflect at different frequencies. We did the same measurement when there was an object present and also when there was no object.

The data of the measurements are represented as acoustic effective pressure values [Pa]. We imported the data to Excel files and calculated real acoustic pressure level for each microphone. After this we can use the formula to calculate sound pressure levels (SPL) for every microphone for each octave.

$$SPL = 20 \times \log\frac{P}{P_0}\ [dB]$$

- P: root mean square of sound pressure
- P_0: reference sound pressure (2.0E-5 Pa)

Afterwards, when we looked at the differences of sound pressure levels with the object and without the object, we were able to compare the data with the other materials.

When we were learning the basic theory of sound propagation, one of the exercises we did to test our knowledge and understand how sound propagates in a free field was to do a numerical model of sound propagating from the sound source using MATLAB-based program Octave.

The following plot (Fig. 15), which is a result of our numerical calculations in Octave, presents how Sound Pressure Level (SPL) changes with distance from the sound source. The sound source is located in the centre of the field (coordinates 0,0).

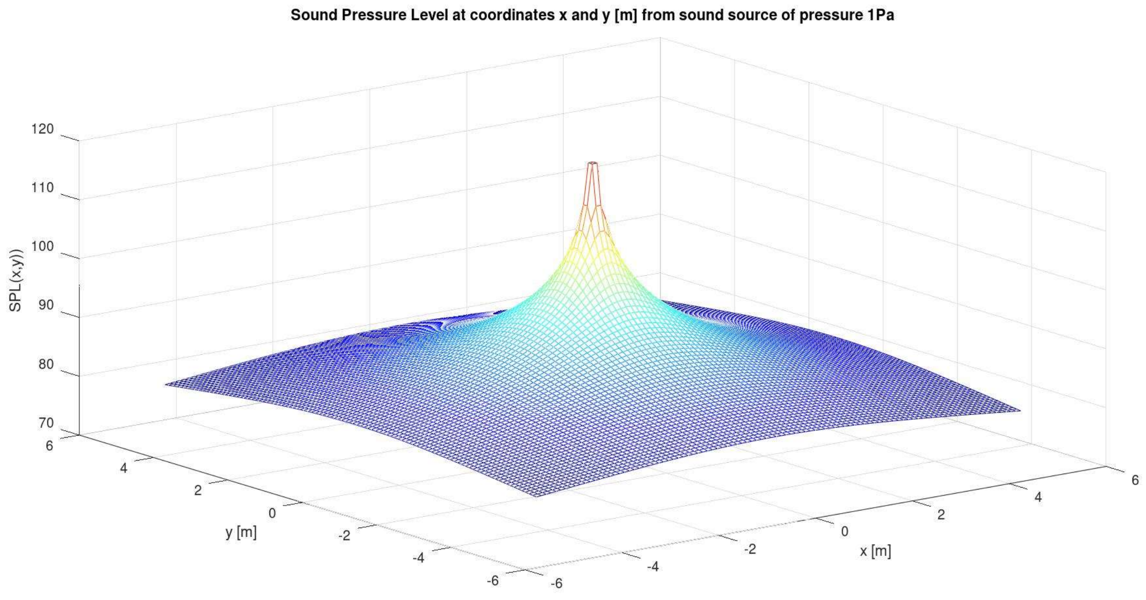

Fig. 15 Plot of SPL in 2D space

3.5 Results

Under the following points there is a presentation of the results we obtained during measurement sessions with the wooden panel, plastic panel, glass window and finally the photo-voltaic panel.

Each measurement returned a set of 500 000 readings of acoustic pressure from each microphone. We processed that data, by calculating standard deviation values from every set and then converting those values to SPL. We then subtracted the values obtained in the measurements without the objects from those with the objects placed in the anechoic room.

The plots included and described in points 3.5.1-3.5.4 present the results of the subtraction, ΔSPL, on the vertical axes and are to be interpreted as the change of SPL caused by the object. The horizontal axes present the exponentially increasing frequencies of sound, which were played during the measurements. Positive values of ΔSPL mean that the level of sound pressure registered by the microphone increased after placing the object in the chamber, while negative indicate the opposite.

Each chart contains three plotlines, which correspond to three microphones. Blue lines represent the first microphone (L1), the closest one to the sound source, yellow ones show the values from the second microphone (L2), which was between the source and the object, and red lines represent the microphone behind the object (L3).

An important notice is that, due to measurement devices' properties, values of SPL can be considered viable only if they are not within the margin of ±6 dB from the measured background noise level. Most of the values, which fall within that margin are the ones at extreme frequencies (16 Hz and 8 kHz), which is why values at these frequencies are not taken into account during the analysis.

3.5.1 Wooden panel

In the following plot (Fig. 16) we can observe that the second microphone (dl2) registered almost no reflection at lower frequencies and an increase at 125 Hz, which topped at 250 Hz with a value around 6 dB. At higher frequencies the reflection started to fall.

The readings from the third microphone show similar behaviour with the lowest frequencies, where almost no absorption happens. At around 250 Hz absorption values start increasing and rapidly spike at 500 Hz, reducing SPL by nearly 25 dB. From there, they gradually decrease with a significant fall at 1 kHz due to object's resonances.

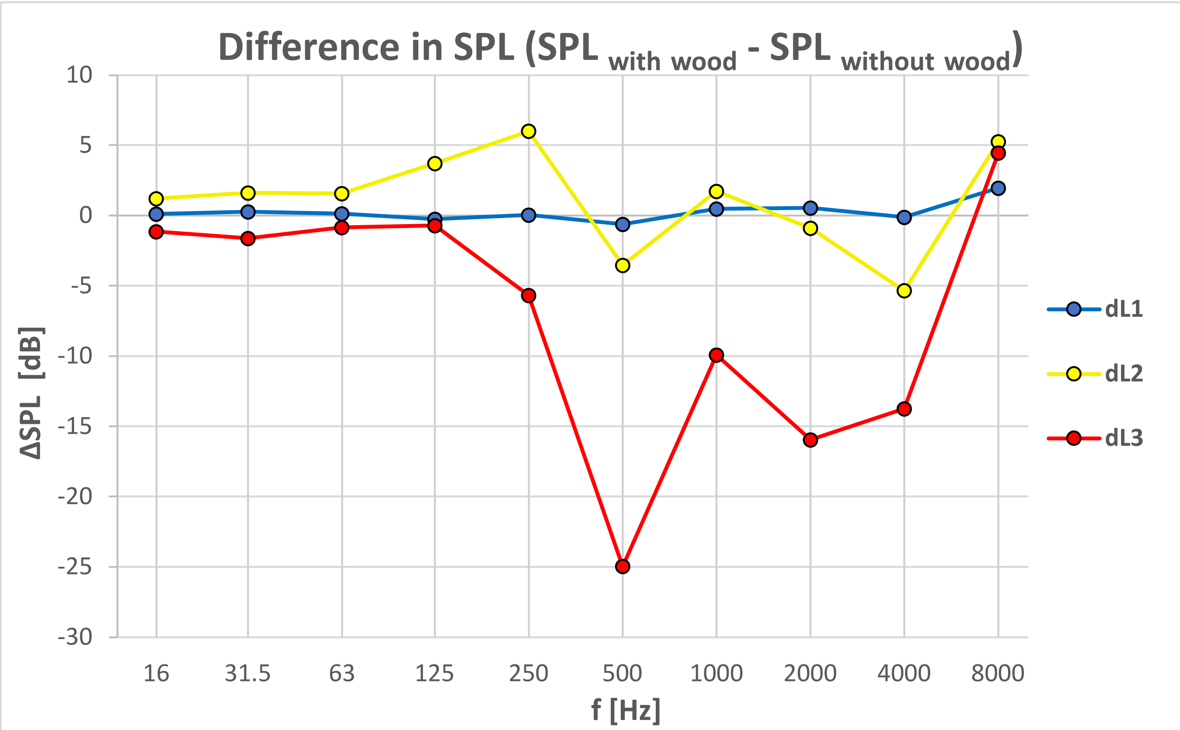

Fig. 16 ΔSPL plot for wood

3.5.2 Plastic panel

The plastic panel showed minor reflection values for nearly every frequency, being the highest at 4 kHz with a value of just above 5 dB.

The third microphone next to no absorption at frequencies up to 250 Hz and a gradual increase that topped at 1 kHz, absorbing around 20 dB of sound pressure level, and from there, slowly decreased.

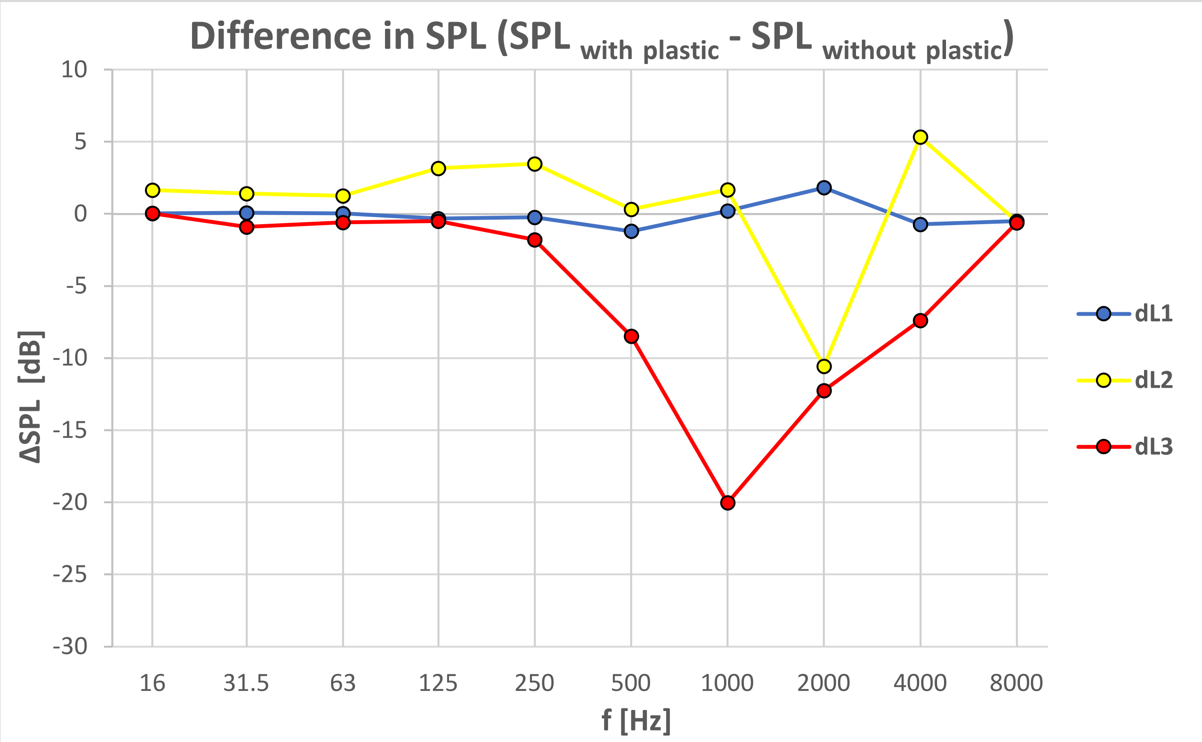

Fig. 17 ΔSPL plot for plastic

3.5.3 Glass panel

The glass window showed relatively high reflection abilities, which increase at around 125 Hz and top at 250 Hz, reflecting around 7 dB. At a frequency of 4 kHz it also reflected over 5 dB, however in the range of 250 – 1000 Hz, we can observe some disturbances.

Similar to the previous objects, absorption values start exponentially increasing from around 125 Hz and reach their maximum at 500 Hz absorbing nearly 24 dB. At higher frequencies, the values slowly fall with a slight deviation from the trend at 1 kHz.

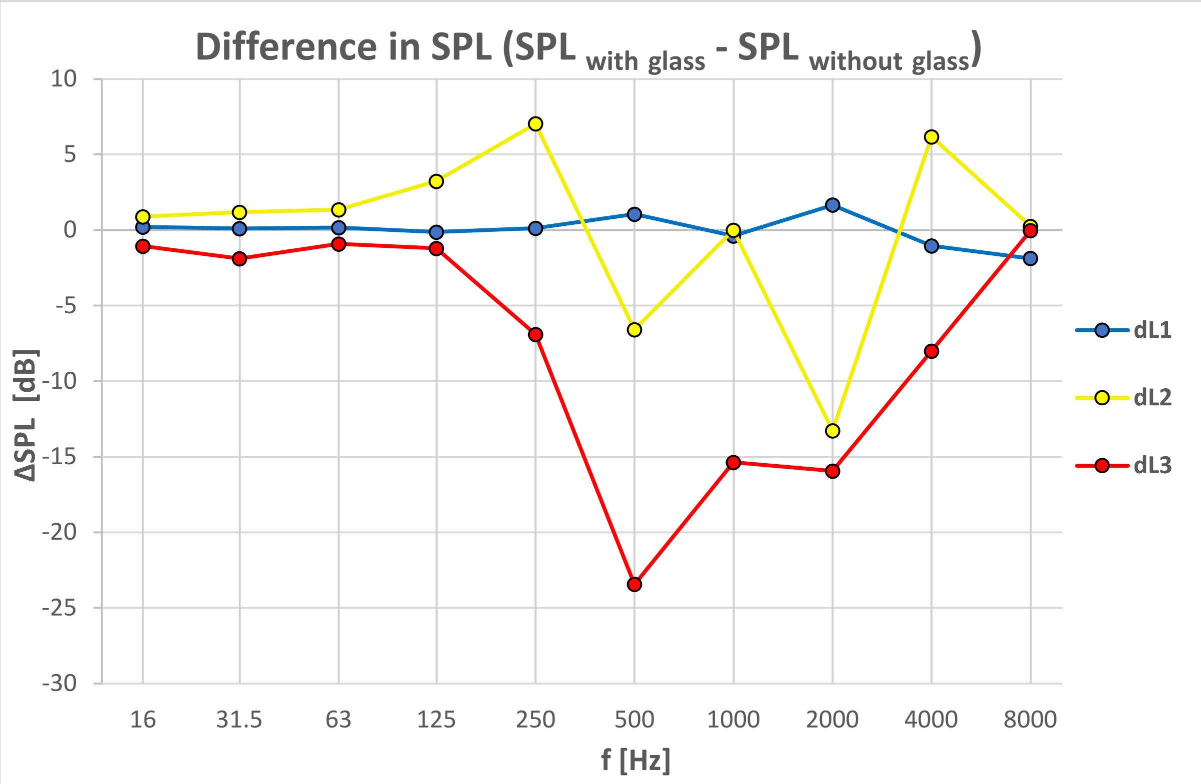

Fig. 18 ΔSPL plot for glass

3.5.4 Photo-voltaic panel

The data results from the measurements on the solar panel showed a relatively high and stable reflection of frequencies in the range of 125 – 2000 Hz with values of 2-5 dB, with an exception of 1 kHz, where the microphone registered a negative value.

Following the trend of other materials, the absorption values rapidly increase from 125 Hz and show a maximum of slightly above 25 dB at 500 Hz. However, the shape of the plot rather resembles a parabola and absorbed sound pressure level decreases much slower.

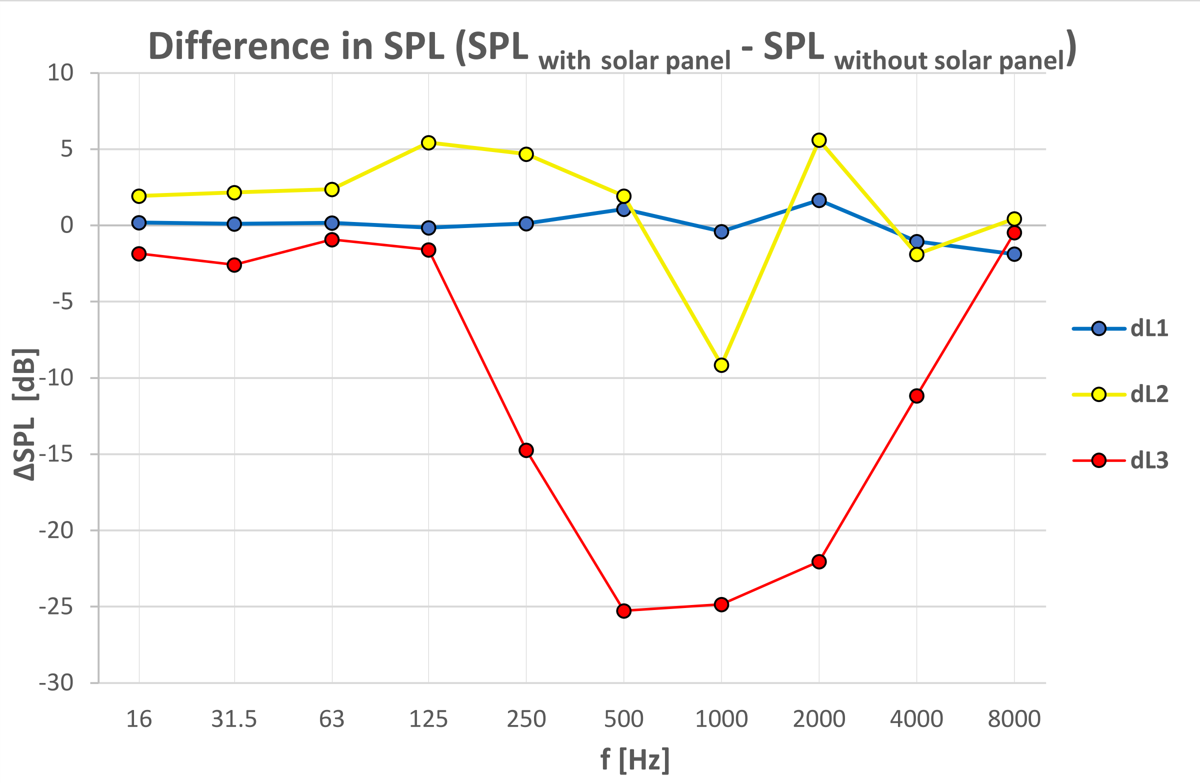

Fig. 19 ΔSPL plot for the solar panel

3.6 Conclusions

Overall, we observed a few similarities among all the objects we tested. None of them reflected or absorbed significant level of sound at frequencies below 125 Hz. It is due to the fact, that soundwaves of low frequencies transfer big amounts of energy. Both reflection and absorption of all materials started increasing around 125 Hz. The maximum absorption values were rapidly reached at 500 Hz, with the exception of plastic (at 1 kHz).

What stood out to us after obtaining these results is that plastic showed the poorest absorption and reflection abilities, the glass and wooden panels were more prone to resonances at certain frequencies. What is more, we were pleasantly surprised with how well the solar panel absorbed a wide range of frequencies, which showed that this object, which is expected to be widely used in the future, has some potential for being used with its acoustic capabilities in mind.

4. Our ideas

When we were approaching the end of the experimental phase it was time to start thinking about the ideas we could propose, that would conclude the whole project. In this chapter we will describe what we came up with after a series of intense brainstorming sessions and additional research.

Part 4.1 will cover two of our ideas, which were more general and based strictly on theoretical research we conducted. We believe that one could help reduce noise levels in open air, outside of buildings and the other might be helpful with making their insides quieter.

In part 4.2 we will go through our third and last idea, which put more effort in and conducted additional detailed calculations in order to make it as comprehensive as we were able to.

4.1 Ideas to help fight with noise

The pace of urbanisation is increasing, and more people move to bigger cities, which significantly raises their population density and means that the nucleus of the future smart city will be really crowded. In fact, the architecture is being developed in such direction, that most of modern buildings in cities are made of glass; it is a trend that will remain in the future and has a true acoustic disadvantage. It is due to the fact that glass, as we have shown before in the experimental results, is very reflective and can make a noisy environment if there is a high density of buildings in one area. It means that if we are in a street that it is surrounded by glass buildings, we may observe echoes and the sound reflected will amplify the overall sound intensity due to continuous reflections of the sound waves. Oftentimes, the distances between buildings create an environment highly prone to creation of standing waves, which only make the problem worse. Our proposal is to consider designing such buildings with an intention of reflecting soundwaves in different directions, as opposed to purely horizontally, using different angles of buildings' facades in order not to reflect sounds directly towards the streets. We imagine that if soundwaves were reflected upwards, the overall sound intensity in the lower, most crowded parts of the city could be reduced.

Fig. 20 Złote Tarasy, Warsaw

The figure above (Fig. 20) presents an example of a building that may easily satisfy this property. The building is a shopping mall, Złote Tarasy, which is one of the most iconic places in the capital of Poland – Warsaw. The design of the glass "dome" certainly targets the reflection of approaching soundwaves more vertically than a standard building and may help avoid the noise amplification in the streets in front of it. Of course, it is a highly unusual design and could not be applied to very tall buildings, but we strongly believe, that with enough effort in research and development in this topic might result in suitable designs even for the tallest skyscrapers. On top of that, though it is a subjective matter, we think that Złote Tarasy is one of many examples, which prove that unusually designed buildings might be highly aesthetic and diversify cities' landscapes.

Our second idea is to look into the interiors of buildings in more detail. Nowadays, many people from the cities live in flats sharing buildings with other families. Most of the ones that have lived in a flat have complained about noise in the above and below floor that surround them. Children running, people playing instruments and partying or even just the TV, those are problems that almost everyone has experienced at least one time in their life. Therefore, while we investigated about it, we discovered that the floors are a big issue. They might not be isolated enough and the materials, which they are constructed from, have poor absorption capabilities while often being highly reflective.

There are two types of noise, airborne noise which comes from the people's voices, phone ringing and TV among others, it travels through the air to make the goal of trespassing the floor or the openings in the wall. The other one is impact noise, which is related to the direct contact with the floor making that the most annoying one.

We have thought of two ways that could improve floor's sound isolation. The first one, the cheaper and easier, is to simply put carpets or similar covers on more walking surfaces. Due to the fact that, the softer material the more sound will be absorbed, and less will be reflected, improving the noise levels both in the same room sounds are generated and in ones surrounding it.

However, the most efficient one is to separate the floor of our house from the raw structure. Afterwards, we put a resilient layer that will separate the structure from the main floor, you can use for instance acoustic mineral wool to isolate the flat. You can include resilient bars and acoustic sealant in the joints. The following figure (Fig. 21) shows a schematic of how such soundproofed floor structure, a floating floor, with these elements, would look like.

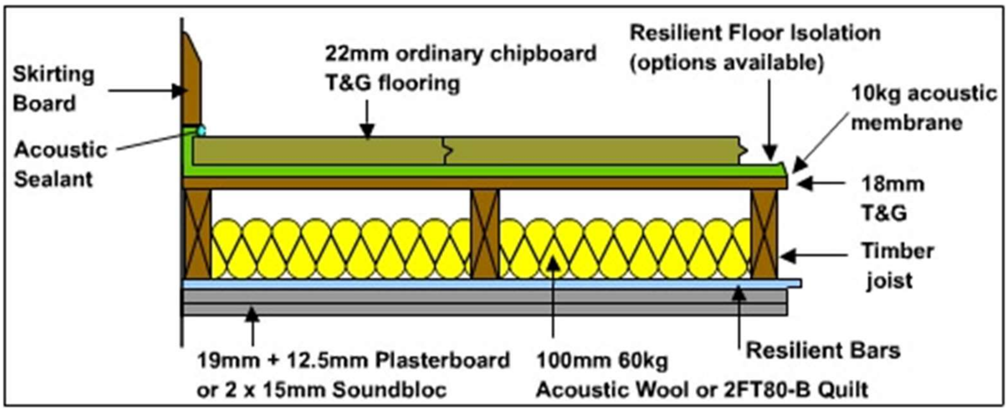

Fig. 21 Diagram of a floating floor
(Noise Control Soundproofing and Acoustics, n.d.)

4.2 Drones and Solar Panels

Our last and most detailed idea was to make use of the data we obtained during our research and experimental phases.

The measurements we performed resulted in interesting data of acoustic absorption and reflection properties of the materials we believe will be crucial or might be useful in the future. We figured that we could look into it and analyse if some of the properties could help with particular future noise problems.

During the brainstorming sessions, which focused on smart cities and noise problems in detail, we observed that all team members agreed on the prediction that drones will be widely used in the future. Whether they will be used as a mean of package delivery or human transport, the size of such drones will definitely be significant, and their propellers will generate substantial amounts of noise.

This is why we decided to investigate that topic further and examine the properties of sound that is produced by a drone.

4.2.1 Drone Data

Thanks to courtesy of our mentor, we obtained a set of data, which was a result of measurements done during one EPS projects he supervised.

The drone was built in Faculty of Mechanical Engineering of Lodz University of Technology and was equipped with eight propellers (280 mm in diameter each) that were equidistantly placed in pair at the opposite sides of the drone (Heliara, Rupp, van Verseveld, Vince & Błaszczak, 2016). We believe that the size and number of propellers of that drone indicates, that it would be capable of delivering packages and it is a good example of a drone, which could be used for that purpose in the future.

Our goal was to examine what frequencies have the biggest intensity in the spectrum of sound produced by that drone. However, in order to obtain it, we needed to do proper calculations on the data we were given and we decided to use MATLAB for that purpose.

4.2.2. Fourier Transforms

The Fourier Transforms, created by Joseph Fourier in 1822 (Fourier, 1822) constitute, by far, one of the best mathematical tools that we have in our time for the data analysis of signals. They allow us to obtain frequencies of any polynomial function. The idea behind them is that, since all the polynomials can be written as a sum of infinite sine and cosine functions, doing this continuous integral transform, you get what is called the frequency spectral of that function, where all the frequencies that participate in the polynomial are shown against their magnitude.

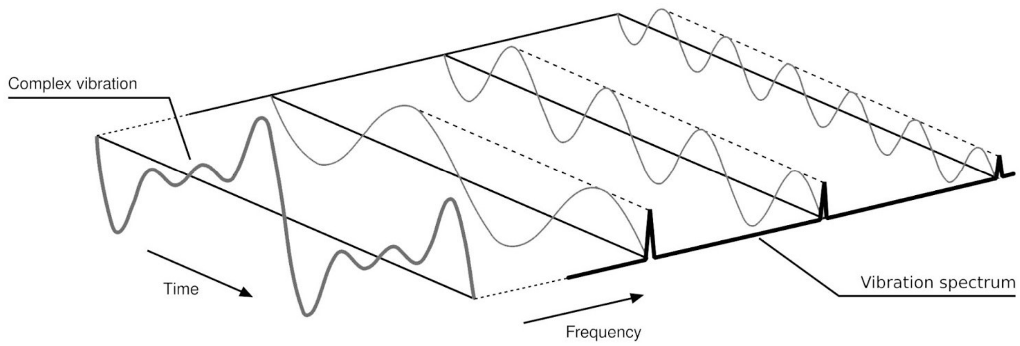

Fig. 22 FFT processing of a complex signal (Power-MI, n.d.)

$$\hat{f}(\xi) = \int_{-\infty}^{\infty} f(x) * e^{-2\pi} \quad dx$$

There exists a multitude of variations of this initial idea, each used in different applications with their own subtleties. For our project we used the Fast Fourier Transform.

4.2.3 Fast Fourier Transform

The Fast Fourier Transform is perhaps the quickest algorithm that can compute the Fourier Transformation. Being the evolution of the Discrete Fourier Transformation, its beginning can be traced down since Gauss in the early 1800s, and it had a big rise in interest in the mid XX century, with the beginning of data analysis.

The element that makes it a key tool in computing science it is its time efficiency, taking the order of only O(n log(n)) instead of O(n^2) as others do. Its algorithm it's very simple yet powerful. It sorts the different power that the polynomials are raised to between pairs and impairs - it needs a number that is a power of 2 to operate, since it needs to have pair root's - and takes advantage of different symmetries, making it faster than any Fourier algorithm.

The efficiency of this algorithm was the main factor behind our choice, because it allowed us to quickly process a big amount of data without powerful hardware.

4.2.4 Spectral Analysis

Used in all kinds of applications in the field of signal processing, spectral analysis is a powerful way to keep track of the frequencies that conforms a signal and, with the precise manipulation, remove the unwanted ones. To do that, it uses the Fourier Transform, explained in the chapters above.

We used the spectral analysis only to know what is the broadcasting frequency of the drone that we tested. To do so, we designed a code using MATLAB, which basically got the data of the acoustic wave previously recorded in the lab as an input and, after applying the Fourier Transform, presented the output as the plot of its frequency vs. the amplitude at it.

4.2.5 Results

After creating the code, we just needed to provide the data of the drone as an input. In order to present everything easier to read, we will show below both plots. The first one corresponding to the data of the acoustic wave generated by the drone at full power and the other one, the plot after Fourier Transform. This last will have on the X-axis a scale from 0 to 8000 Hz, corresponding with the frequencies that we used in the experiment. The following 3 pairs of plots represent readings from 3 microphones, which were placed at different distances.

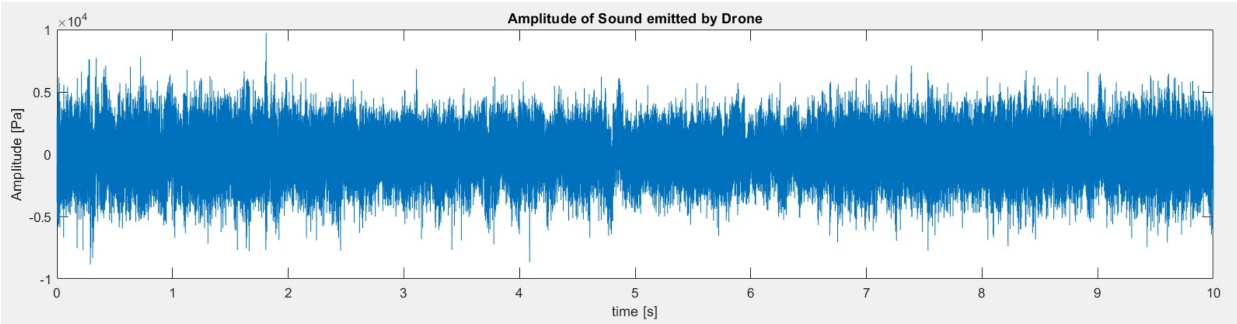

Fig. 23 Drone measurements from microphone 1

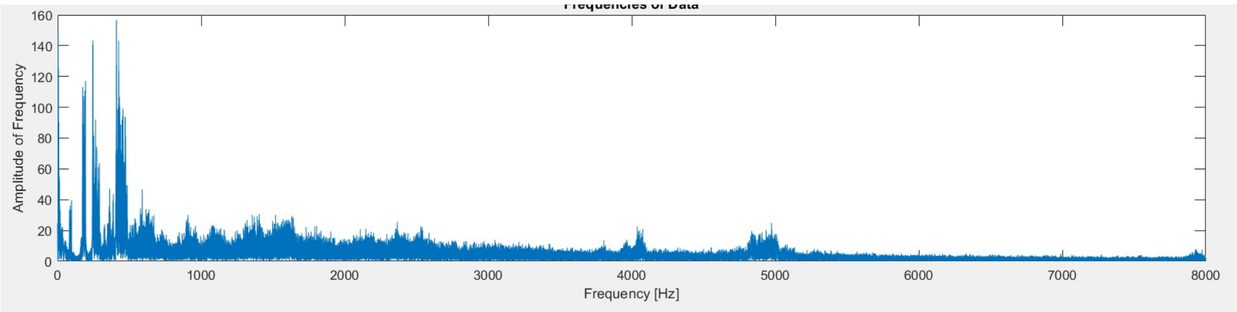

Fig. 24 FFT results of data from microphone 1

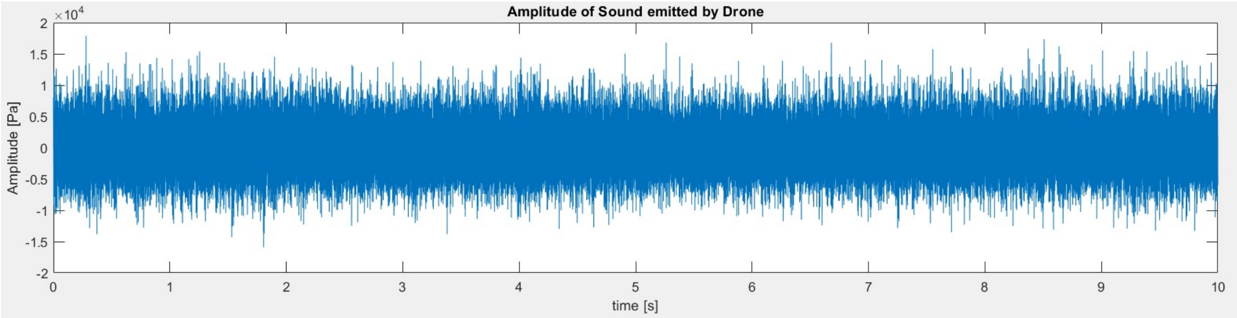

Fig. 25 Drone measurements from microphone 2

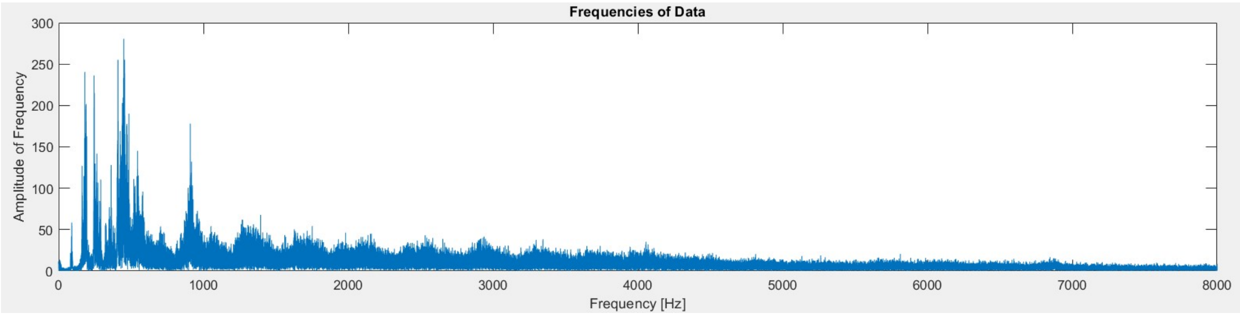

Fig. 26 FFT results of data from microphone 2

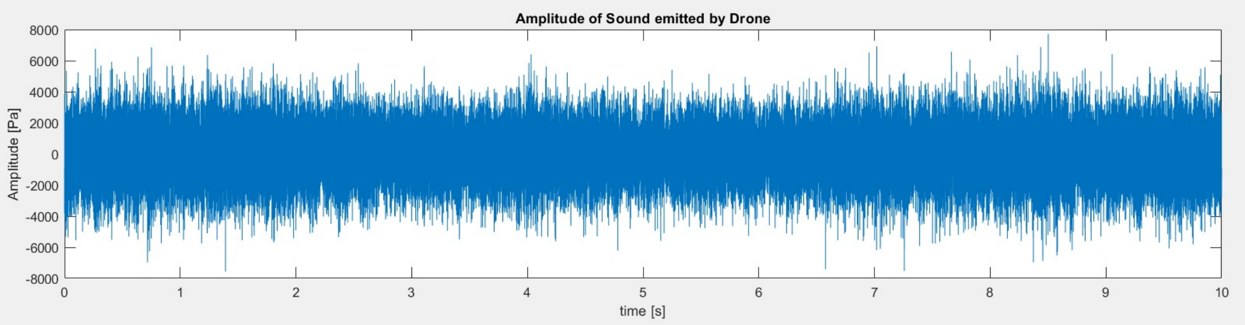

Fig. 27 Drone measurements from microphone 3

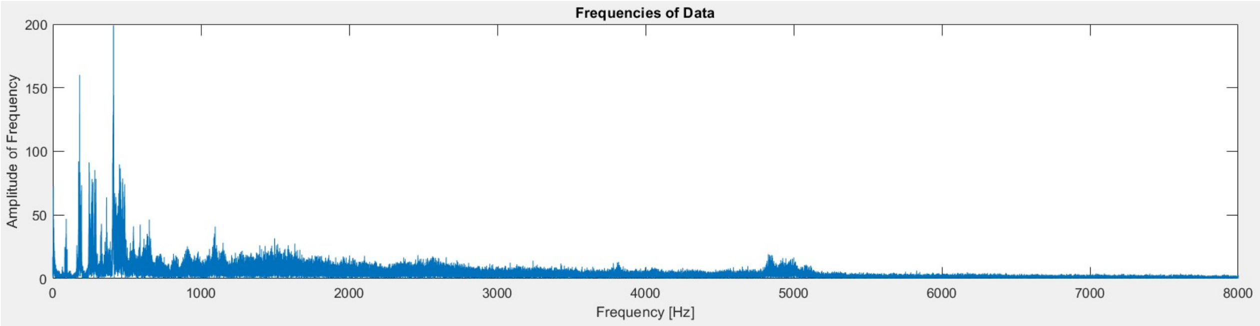

Fig. 28 FFT results of data from microphone 3

We detected spikes in the frequencies below 1000 Hz. In MATLAB, by clicking on the points of maximum values, we can obtain the exact frequencies and their amplitudes.

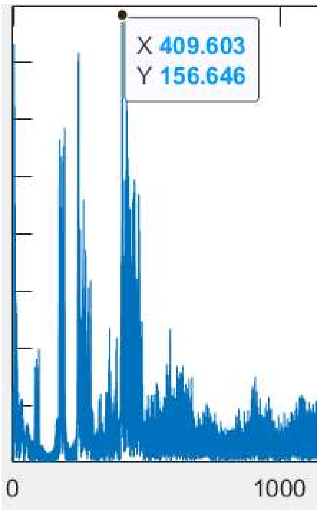

Fig. 29 Point of max. value - microphone 1

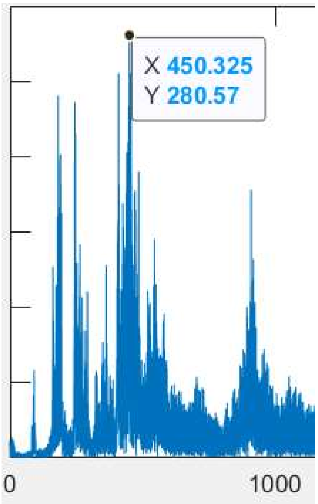

Fig. 30 Point of max. value - microphone 2

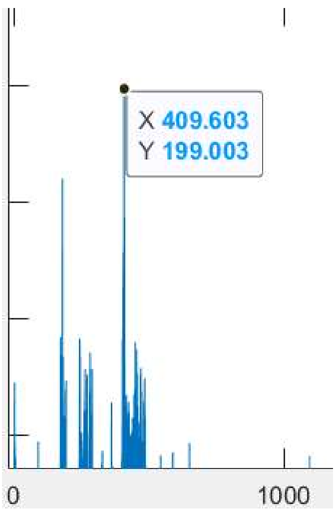

Fig. 31 Point of max. value - microphone 3

As we see, the main frequencies are around 409 and 50 Hz. If we do a weighted average to know the main frequency but also considering its amplitude, we obtain the broadcasting frequency:

$$\bar{f} = \frac{\sum_1^3 f_i * A_i}{\sum_1^3 A_i} = \frac{409.603 * 156.646 + 450.325 * 280.57 + 409.603 * 199.003}{156.646 + 280.57 + 199.003} = 427.56\ Hz$$

With this result we proceeded to further analyse our own measurements from chapter 3 and formulate our third idea.

4.2.6 Idea with solar panels

Altogether, we have got that the main frequency that Octocopter broadcasts is 427.56 Hz, that we can safely approximate to 430 Hz for simplification, barely losing any precision.

We looked at the data and the plots from point 3.5 and found that one of the tested objects performed superbly at absorbing this particular frequency: the solar panel.

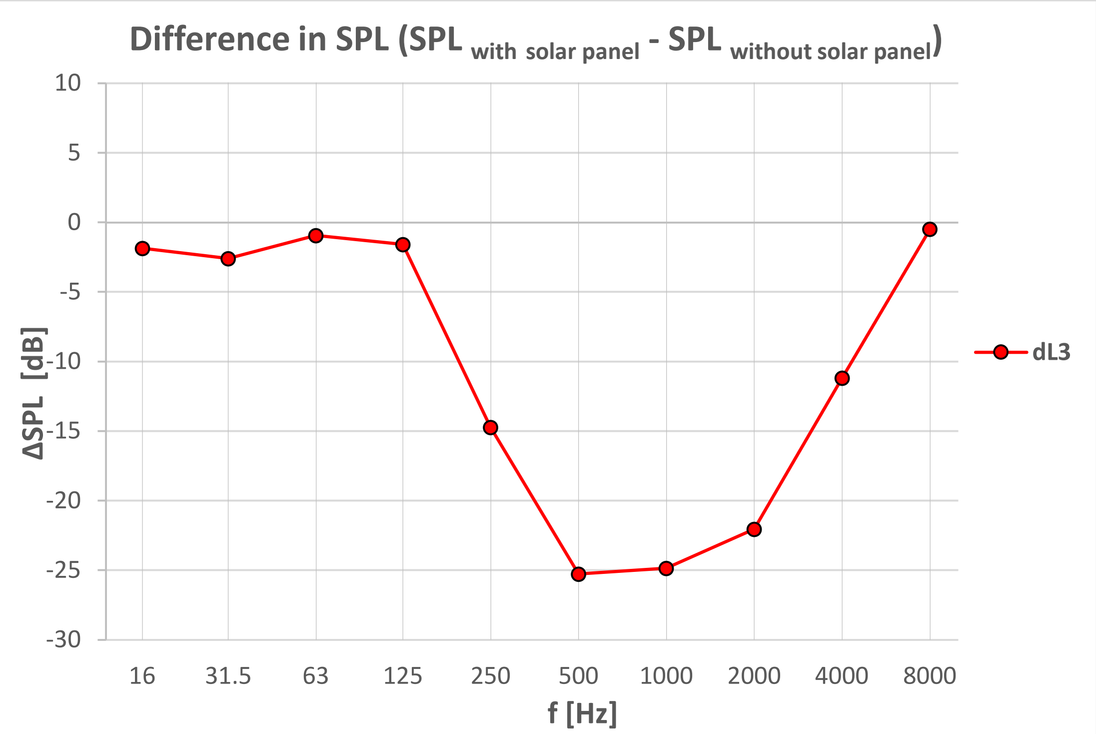

Fig. 32 ΔSPL plot for the solar panel - L3 microphone only

If we investigate the graph (Fig. 32), we can see that, at 430 Hz there is a drop of SPL of about 24 dB. It means that, with a solar panel between the drone and the building, we would get a quite significant amount of noise reduction, just by using the properties of the materials, that we discovered in the laboratory.

Following from there, our proposal is simple, clear, yet efficient. Considering that the drones always fly at a significant height, almost at the top of the buildings, we came up with an idea of using solar panels as an acoustic cover that could help prevent a potentially significant problem of noise pollution caused by drones while serving an additional purpose of generating clean energy.

However, the exact application of photo-voltaic panels for that purpose is yet to be defined and developed. Nevertheless, we briefly brainstormed on that topic and concluded with one example of such application.

We think that this idea could be combined with the first one we described in point 4.1, which focused on angling of buildings' facades. In that scenario, we believe that, alternating with glass from the windows, buildings could be covered, to some extent, with solar panels. That would not only help with reduction of noise inside the buildings, but also would result in creation of a powerful source of renewable energy for the city. If a big number of buildings had large parts of their facades shielded with solar panels, the amount of energy from different and not so ecological sources needed for that city would be significantly reduced.

Conclusions

This project has been really challenging for us due to a number of reasons. None of us had been really familiar with the topic of acoustics and smart cities. We needed to do a huge amount of research to compile enough information and spend a lot of time brainstorming and exercise our creativity in order to achieve our personal points of view on the project's topic, which turned out to be much more complex than we had expected. However, with the help of our mentor and the continuous communication between the members, we have achieved a common goal and developed a comprehensive overview of the topic.

Firstly, within a short period from our first meeting, we developed a set of rules that dictated the organisation of our work throughout the semester. We managed to overcome the obstacles created by pandemic-caused remote learning and efficiently work collaboratively in these difficult times.

We have also established a common in-depth view on how we see the future smart cities. We decided that they will be places grouped by 'spheres of life', where every inhabitant will have everything they need to lead a productive and fulfilling life in a city within a close range. The housings will be in towering skyscrapers, that will have its inside space distributed in both housings and working places. On the exterior, the concept of streets as we know them will disappear, creating sizable green spaces and open areas where people will spend their free time. To solve the large amount of energy needed to make the city work, we also argue that renewable energy sources will be integrated into the buildings.

What is more, the approach to transport in the city will drastically change. It is our belief that there will be much more focus on close-range public transport and commuting to distant parts of cities will move underground, in big highways that can connect all the 'sphere' city in a brief time, also with the help of smart cars.

Furthermore, we talked about drones and how we think they will revolutionize our lives, including those in the cities. This will result in a great number of drones flying around the city, creating, what we think, the most significant new noise problem.

We also managed to take advantage of Lodz University of Technology's equipment and tried our hand at making measurements in an anechoic chamber, where we experimented with acoustic properties of diverse objects: wooden and plastic panels, a glass window and a solar panel. We learned how to treat, understand, and analyse acoustic pressure data.

Lastly, we learned how to gather and process various types of information and conclude all the activities with our own creative ideas on how such a major problem like noise pollution could be fought. We developed three simple ideas, which we believe could reduce overall noise levels inside buildings or in the streets and, hopefully, help mitigate their impact on human health. Even though our work did not result in creation of a ready-to-implement solution or a product, we are happy with what we learned and how well we managed to complete every task. And, most importantly, we are proud of what we achieved and strongly hope, that the results of our work will help create better, quieter and safer smart cities.

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