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RESEARCH ON INNOVATIVE ENERGY HARVESTING TECHNOLOGIES AND THEIR APPLICATION IN THE BUILT ENVIRONMENT

Master's Degree Final Project

Supervisor

Assoc Prof. Dr. Rasa Apanaviciene

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DECLARATION OF ACADEMIC INTEGRITY

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Kaunas

I confirm that the final project of mine, **Hariharasubbu Balamoorthy**, on the subject "**RESEARCH ON INNOVATIVE ENERGY HARVESTING TECHNOLOGIES AND THEIR APPLICATION IN THE BUILT ENVIRONMENT**" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources; all direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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Kaunas, 2018. January, 81 p.

SUMMARY

The Final Master Project involves with research work on new energy harvesting technologies, its construction methodologies, and applying them as constructions by utilizing the land area in the Nemunas River Island Park where a Science Museum is proposed to be constructed. The thesis reviews various literatures supporting the ideas of different innovative energy harvesting technologies such as Photovoltaic dome, Photovoltaic Trees, Photovoltaic Floor, Wind Energy Trees, Piezoelectric Rain Farm, Luminescent roads and their present scenarios in various countries around the globe in the first part of the work. It then explains the methodology of their construction technologies and energy harvesting calculations in the second part. In the third part, the research work implies the application of the said energy harvesting elements as constructions on a real time project around Science Island Museum in the Nemunas River Island, Kaunas City. The real time application takes into account the surrounding area of the proposed museum in the Nemunas River Island for installation of innovative renewable energy harvesting structures through Landscape architecture. These structures are proposed as a part of the exterior Science Island Museum project. Three different layouts, 3D model of the landscape, Energy calculations and the cost estimation analysis were presented in the third part. The thesis work concludes with the application of the research work as a proposal in the Science Island Park area with their total energy calculations showing a significant role in powering up the park area of the proposed Science Island Museum.

The thesis report is 81 pages excluding the Annexures and Appendices and includes Introduction, 4 chapters, Conclusions, Dissemination of the Results, Acknowledgement, and References. The Thesis consist of 52 Figures, 7 Tables, 8 Formulae, 66 Bibliographical entries, 3 Annexures and 1 Appendix.

Hariharasubbu, Balamoorthy. Inovatyvių energijos gavybos technologijų ir jų taikymo užstatytoje aplinkoje tyrimai. Magistro baigiamasis projektas / vadovas doc. dr. Rasa Apanavičienė; Kauno technologijos universitetas, Statybos ir architektūros fakultetas.

Mokslo kryptis ir sritis: Technologijos mokslai, Statybos inžinerija

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Kaunas, 2018. 81 p.

SANTRAUKA

Baigiamasis magistro projektas apima naujų energijos gavybos technologijų ir jų panaudojimo statiniuose mokslinius tyrimus, pritaikant juos Kauno Nemuno salos teritorijoje, kurioje siūloma statyti Mokslo Salos muziejų. Pirmoje baigiamojo projekto dalyje analizuojama literatūra apie inovatyvių energijos gavybos technologijų statinius, tokius kaip: fotovoltinis kupolas, fotovoltiniai medžiai, fotovoltinis grindinys, vėjo energijos šaltiniai, pjezoelektrinio lietaus miškas, liuminescenciniai keliai, ir jų dabartiniai pritaikymo scenarijai statiniuose įvairiose pasaulio šalyse. Antrojoje dalyje analizuojamos šių statinių statybos technologijos ir energijos gavybos skaičiavimai. Trečiojoje dalyje pateikiamas minėtų energijos gavybos elementų kaip statinių panaudojimas realiame projekte aplink planuojamą Mokslo Salos muziejų Kauno miesto Nemuno saloje. Realiame projekte atsižvelgiant į Nemuno upės salos aplinką formuojama kraštovaizdžio architektūra novatoriškiems atsinaujinančios energijos šaltinių statiniams įrengti. Šie statiniai siūlomi kaip Mokslo Salos muziejaus išorinio projekto dalis. Pateikti trys skirtingi scenarijai, 3D kraštovaizdžio modelis, energijos skaičiavimai ir statybos laiko ir sąnaudų įvertinimo analizė. Baigiamojo magistro projekto trečioji dalis pristatoma kaip tiriamasis- taikomasis mokslinių tyrimų darbas ir kaip projektinis pasiūlymas Mokslo salos muziejaus teritorijoje įrengti inovatyvių energijos gavybos technologijų statinius, kurie pagal energetinius skaičiavimus galėtų didžiąja dalimi aprūpinti Nemuno salos parką elektros energija.

Magistro baigiamąjį projektą sudaro 81 psl. be priedų. Projektą sudaro įvadas, 4 skyriai, išvados, rezultatų sklaida, padėka, literatūros šaltinių sąrašas. Projekte yra 52 paveikslai, 7 lentelės, 8 formulės, 66 literatūros šaltiniai ir 4 priedai.

To my Mother and all my Mentors, I couldn't have done this without you.
Thank you for all the support along the way. Finally, All the Glory to God.

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Acronyms, Abbreviations, Units and Terms

3D	– Three Dimensional
ACEEE	– American Council for an Energy-Efficient Economy
BIM	– Building Information Modelling
BIPV	– Building Integrated Photovoltaics
et al	– *et alia* (Latin), and others (English)
cm	– centimeter(s)
CSP	– Concentrating Solar Power
Eq.	– Equation
EU	– European Union
Fig.	– Figure
GPS	- Global Positioning System
GW	– Gigawatt(s)
GWh	– Gigawatt(s) hour
HVAC	– Heat, Ventilation and Air conditioning
IEA	– International Energy Agency
i.e.	– *id est* (Latin), that is (English)
kW	– kilowatt(s)
kWh	– kilowatt(s) hour
kWh/ m^2	– kilowatt(s) hour per square meter
kWh/ an	– kilowatt(s) hour per annum
LASER	– Light Amplification by Stimulated Emission of Radiation
m	– meter(s)
m^2	– square meters
MW	– Megawatt(s)
MWh	– Megawatt(s) hour
MWh/ an	– Megawatt(s) hour per annum
PV	– Photovoltaics
PVGIS	– Photovoltaic Geographic Information System
UK	– United Kingdom
US	– United States of America
VR	– Virtual Reality
WBS	– Work Breakdown Structure

INTRODUCTION

In a world where the future of non-renewable energy is dwindling than ever before, and it has become necessary to look for alternate energy harvesting, this thesis researches different innovative energy harvesting technologies and their construction technologies. While the innovations of energy harvesting technologies are rapidly being researched and engineered, the Governments around the world have been trying to reduce Carbon emission through implementation of Green energy Policy and Energy efficient constructions. In the following chapter, various real time projects and Regulatory policies of different countries are analyzed and ideas on different innovative energy harvesting technologies are explored through various scientific and general literature. Having said that, the construction technologies being used to install such energy harvesting structures are creatively developed and implemented in recent years. Among the very new trending construction technologies, Augmented and Virtual Reality Designing and Analysis is the most explored technology as it incorporates real time Building Information Modelling and literature about that are also presented. The Aim and Objectives of the Final Thesis Project is also discussed.

1. RECENT TRENDS IN INNOVATIVE ENERGY HARVESTING TECHNOLOGIES

1.1 ACTUALITY OF THE TOPIC PRACTISED IN DIFFERENT COUNTRIES

Innovative Energy Harvesting Technologies – Present Scenario

After the Paris Agreement signed in 2016, all the signatory and party countries have aimed to reduce the Green house emission through various means. Harvesting clean energy is one of the main areas that most developing and developed countries around the world are trying to implement. According to 2007 worldwide Public opinion survey, there has been a growing support for implementing clean energy harvesting such as energy from solar power and wind power (United Nations Environment Programme, 2007). Researchers and Engineers around the world have been trying to design and construct the most efficient way of harvesting clean energy. While the traditional clean energy harvesting structures were constructed separately, a recent report finds that new innovations in clean energy harvesting is the siting of two different technologies in the same location, to make use of shared land, grid connections and maintenance, and to reduce intermittency (Frankfurt School-UNEP Centre, 2017).

There has also been new areas of clean energy harvesting other than the Solar Energy and Wind Energy. Engineers from Lancaster University have been doing research on piezoelectric smart materials, which when embedded in road surfaces can harvest energy from vehicle vibrations (phys.org, 2017). Research in Piezoelectric Energy harvesting structures is booming and may become competing with that of Solar Photovoltaics and Wind Turbines. On the other side of the Globe, researchers from the Okinawa Institute of Science and Technology revolutionized harvesting energy from Ocean tidal waves (Okinawa Institute of Science and Technology Graduate University, 2017). However, at present, constructing combination of multiple energy harvesting structures have become more efficient than the traditional way. One of the other exciting and trending green construction technology is the glowing roads. They do not require electricity but just natural sunlight to glow in the dark. That said, these are achieved by specially engineered glow in the dark materials. Dubbed as "Smart Highways", a 500m stretch of highway in the Netherlands uses road markings that are light-absorbing and glow-in-the-dark instead of streetlights (Clark, 2014). There has also been research going on in recent years involving piezoelectric materials and solar PVs to make the road glow in the night without using street lights. An US based construction company reported Energy saving constructions to be one of the new trends to be watched in 2017 in the field of Construction technology (South Bay Construction , 2016).

According to Bentley Software, the various significant construction technologies that Civil Engineers look forward to implement in the near future for constructing Renewable energy harvesting projects and other general construction projects are (Alderson, 2017):

- Data Patterns Detection;
- Cross-Discipline Collaboration;
- Next level BIM incorporating Augmented and Virtual Reality (VR) Modelling using LASER and Drones.

VR 3D modelling is a fast emerging construction technology that is useful in designing and analyzing a construction by applying in virtually Built Environment, before being actually constructed.

Present Scenario in the UK

In the Green energy construction sector, UK is keen on implementing various renewable energy harvesting constructions. The Cleve Hill installation, a private sector project is alleged to be the largest Solar Farm by the year 2020 in the UK and is being constructed with a generation capacity of 350 MW over a land area of 900 acres of the Kent countryside. This construction project estimates to generate enough electricity to power as many as 110,000 homes (McArdle, 2017). It is not just solar energy harvesting constructions that UK concentrates but also has cemented its status as a world leader in offshore wind, with 29 wind farms generating 5% of national energy demand (McArdle, 2017). It is expected to increase in the next couple of years to 10%. The 2009 Renewable Energy Directive predicted a sharp increase in the construction of Renewable Energy harvesting technologies in the following decade (National Renewable Energy Action Plan for the United Kingdom, 2009). This could be seen in Fig.1. However, as of November 2017, UK lags behind the target set by the European Union Directive for 2020.

UK mostly applies Photovoltaic technologies as either Building Integrated or Roof-top assembly. The Solar Park in Kent is an exceptional stand-alone structure. It should be observed, that many Universities around the UK are putting intensive research into other forms of energy efficient technologies like Bio and Chemi- Luminescence, Living Wallpapers or Bio-Photosynthesis Solar energy harvesting technology (Cooke, 2017). Pavegen, a UK based company is creating walkable pavement tiles that generate energy from mechanical stress of the people walking.

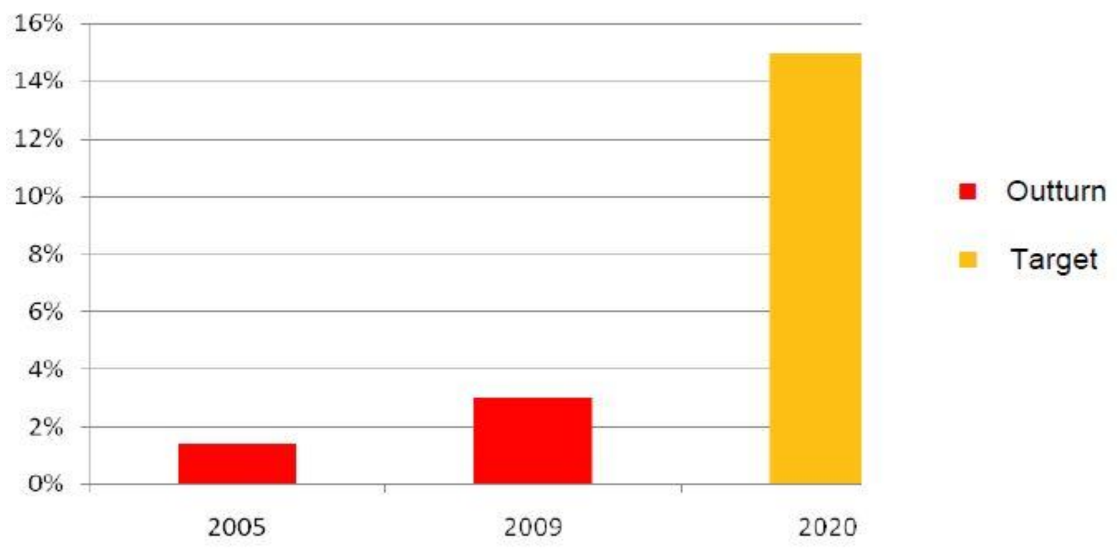


Fig. 1. Energy consumed from Renewable Energy Sources in the UK*, 2009. [Source: Image was retrieved from the document downloaded from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47871/25-nat-ren-energy-action-plan.pdf]

*Outturn data from *Digest of UK Energy Statistics* (2009) http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx

Present Scenario in India

Unlike a developed country like that of the UK, India is a super-fast developing Economy similar to Lithuania. While India is a vast country in size, its geographical positioning on the world map gives it a vast potential in accessing abundant Renewable Energy; i.e. there is plenty of sunlight and Seas and Ocean on all three sides of its South. In recent years, India has shown more interest into construction of Renewable Energy harvesting structures.

In case of Solar Energy, as of 2017, India has constructed the World's largest Solar park (Jaiswal & Bhagavatula, 2017). China had hold the fame previously with an 850 MW PV Solar plant earlier. The Indian PV Solar Park at Kurnool is estimated to be 1000 MW. Although the construction has only been completed for 900 MW, the Government of Andhra Pradesh Province has already started plans to construct a new 1500 MW project at Kadapa (Jaiswal & Bhagavatula, 2017). While India's operational solar power capacity stands at 15.6 GW as of the end of October 2017, with numerous Mega-projects to be constructed in the next couple of years, the Government expects to exceed its current target of 100 GW of Solar power by 2022 (Mahapatra, 2017).

India had already invested in Wind Farms, even before Photovoltaic Solar Technologies. Despite all these Energy harvesting constructions, energy efficient building construction of Green Buildings is still not very popular among the Indian Citizens. Unlike UK and other European Countries, where Building Integrated Photovoltaic Technologies or Rooftop Solar panels are very popular in common office and residential buildings, the idea of these innovative energy harvesting technologies and constructions are yet to become popular among the common people of India. This could be attributed to many socio-political reasons existing in the country. It should also be observed that most Solar panels are imported from European Countries like Germany, Switzerland, etc. and hence are not economically viable for most section of the society. In 2013, Governments of India and Switzerland signed a Memorandum of Understanding (MoU) to use the Swiss expertise in constructing energy efficient buildings in India. The Indo-Swiss project on Building Energy Efficiency Project (BEEP) brings together builders, developers and state agencies, among others, to promote energy efficient designs for new buildings (Press Trust of India [PTI], 2013).

The Energy Statistics for 2017, as seen in Fig.2, estimates 62% of solar power and 34% wind power as potential renewable power till the early 2016 (Central Statistics Office, Ministry of Statistics and Programme Implementation, 2017). In India, the type of Photovoltaic technology installation varies over a wide range. According to a Report from International Energy Agency, as of 2015, Utility-scale solar photovoltaic (PV) projects with capacity of 4 GW have been constructed. On the other hand, Rooftop PV installations of 450 MW of capacity have been constructed as of 2014 and are still very slower in implementation across the country. The newest trend in the market is the Concentrating solar power (CSP). This only has 200 MW of capacity constructed and in operation ((India Energy Outlook, 2015, pp. 124-127).

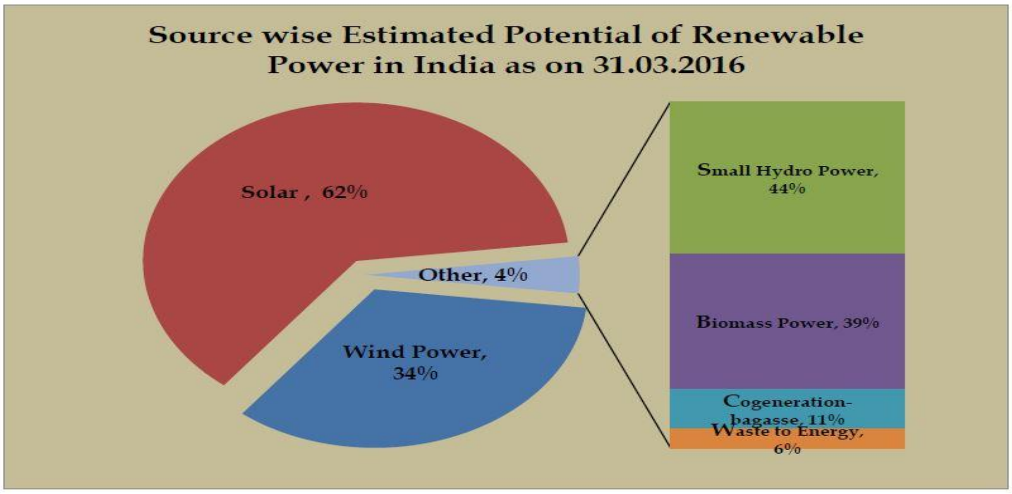


Fig. 2. Estimate of Renewable Power Sources in India as on March, 2016. [Source: Image retrieved from (Energy Statistics, 2017, p. 5)]

Present Scenario in other European Union Member Countries

Most of the European Union members are very keen on the EU Directive on Energy efficient constructions and have implemented an Action plan to ensure the target is achieved by 2020. The share of energy from renewable energy sources of the different EU member countries is shown in Fig. 3. In the following pages, different European Countries are compared with Lithuania in the Renewable energy production. It should be observed that all countries compared with Lithuania belong to the European Union member countries except for Russia.

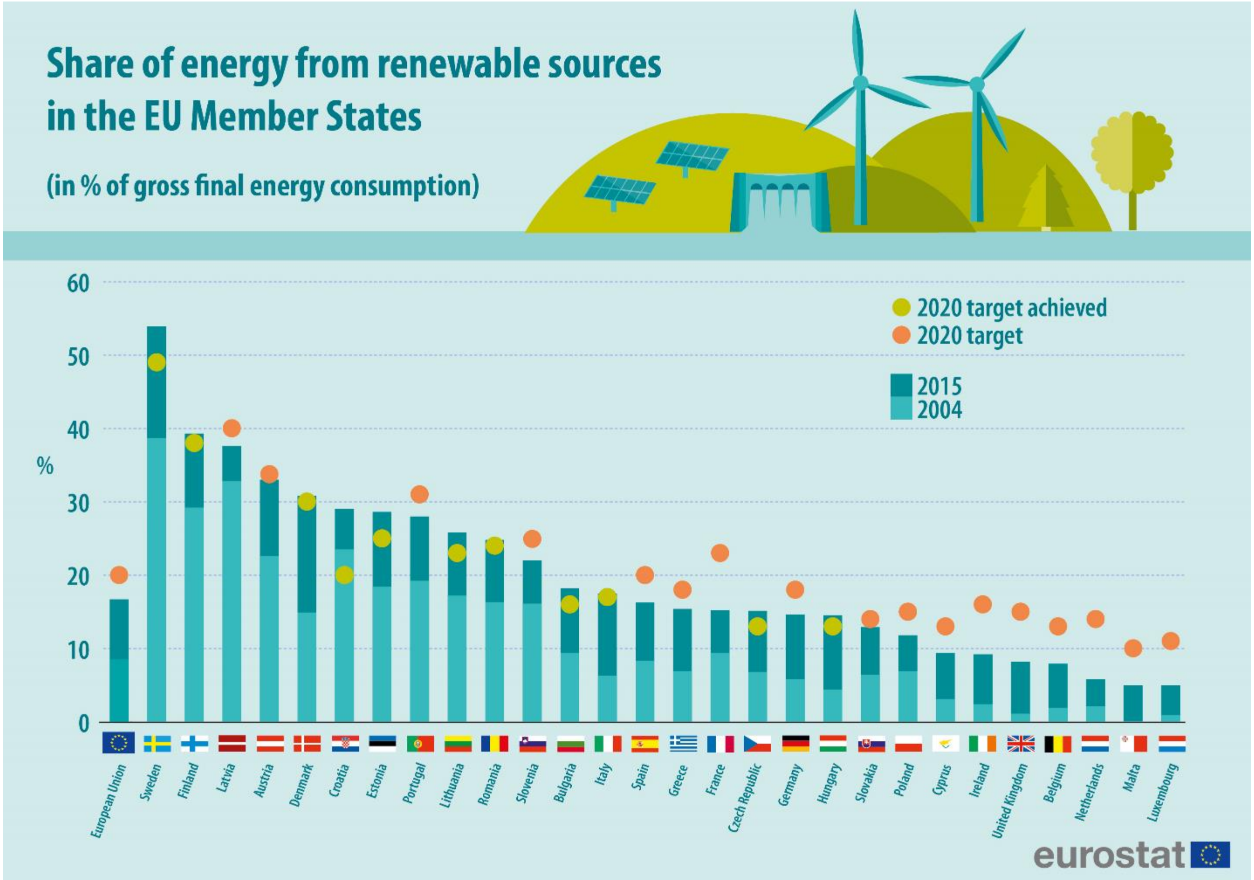


Fig. 3. Share of Energy from Renewable Energy source by EU Countries, 2017. [Source: Image retrieved from News Release document, which was downloaded from http://ec.europa.eu/eurostat/documents/2995521/7905983/8-14032017-BP-EN.pdf/af8b4671-fb2a-477b-b7cf-d9a28cb8beea]

According to the International Energy Agency, It could be observed that Germany is leading in the amount of Renewable energy production when compared with Lithuania (Fig.4). On the contrary, Lithuania leads Germany in the share of Renewable energy in Total Energy production while UK lags behind both Lithuania and Germany. (Fig.5).

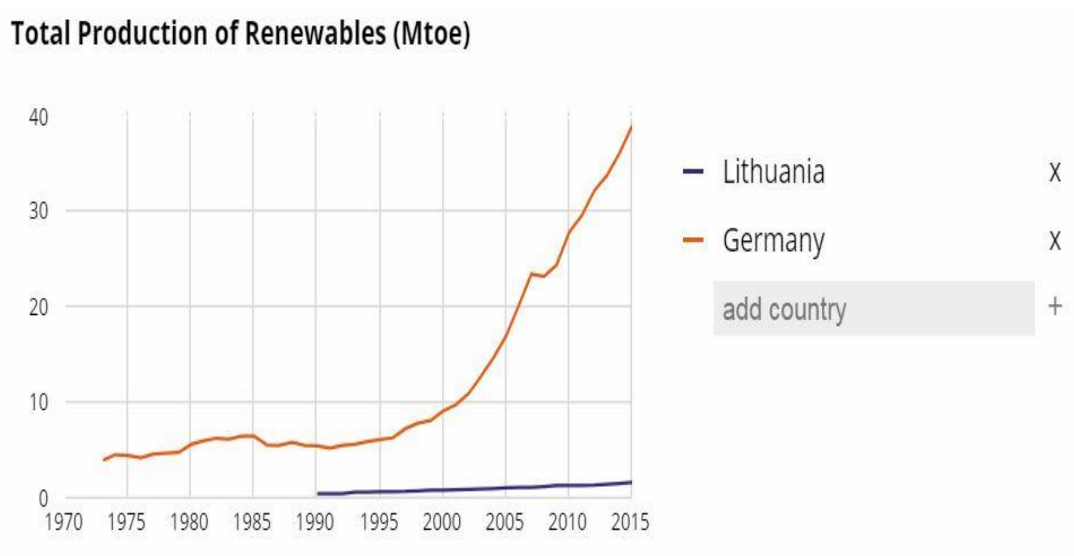


Fig. 4. Renewable Energy Production – Comparison between Lithuania and Germany from 1970 - 2015. [Source: Image generated and retrieved from http://energyatlas.iea.org/#!/tellmap/-1076250891]

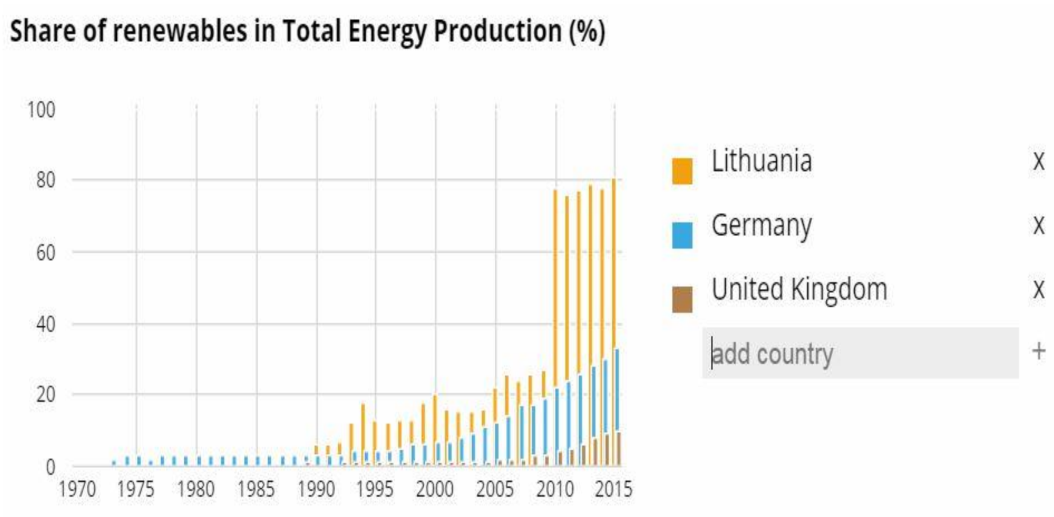


Fig. 5. Renewable Energy share in Total Energy Production – Comparison between Lithuania, Germany and UK from 1970 - 2015. [Source: Image generated and retrieved from http://energyatlas.iea.org/#!/tellmap/-1076250891]

Another interesting observation is that Latvia, the neighboring country to Lithuania in the Baltic region, actually leads Lithuania in the share of Renewable energy in Electricity production (Fig. 6). On the other hand, Lithuania shares more renewable energy in total electricity production than Russia (Fig.7).

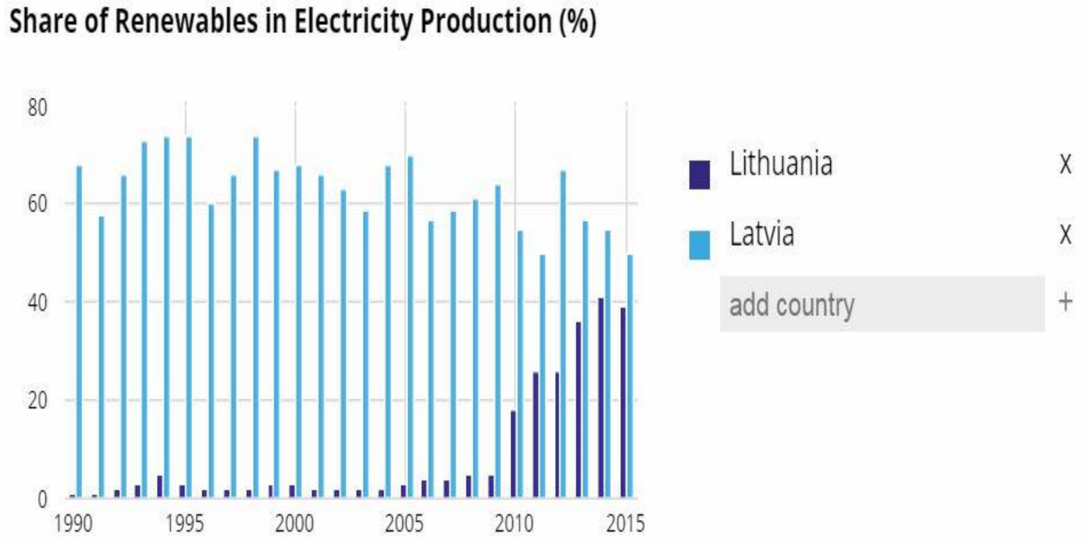


Fig. 6. Renewable Energy share in Total Electricity Production – Comparison between Lithuania and Latvia from 1970 - 2015. [Source: Image generated and retrieved from http://energyatlas.iea.org/#!/tellmap/-1076250891]

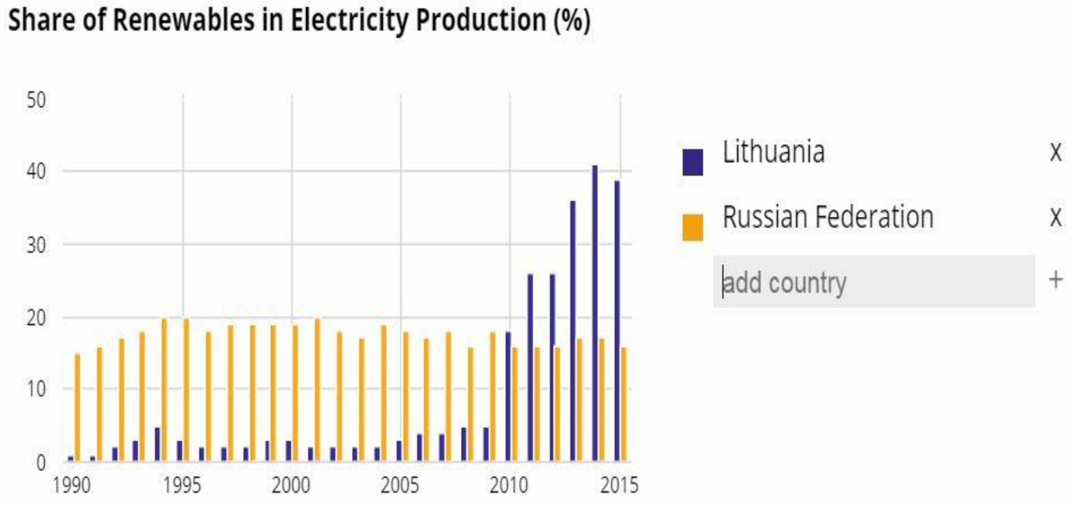


Fig. 7. Renewable Energy share in Total Electricity Production – Comparison between Lithuania and Russia from 1970 - 2015. [Source: Image generated and retrieved from http://energyatlas.iea.org/#!/tellmap/-1076250891]

From Figures 4 – 7, it is evident that the Renewable Energy market has increased over the years and construction of such structures are rapidly growing. The most important factor that drives this growth can be attributed to the Energy Efficient Construction policy and Directives that are being implemented by the European Union from time to time. With the advancing construction technology such as the next generation BIM with VR, the construction of innovative energy harvesting structures is getting easier every day. It should also be observed that: when it comes Energy efficient constructions, it is not just always about renewable energy generation but also includes thermal insulation, passive solar lighting, etc. The energy efficiency scorecard of different world countries is shown in Fig. 8.

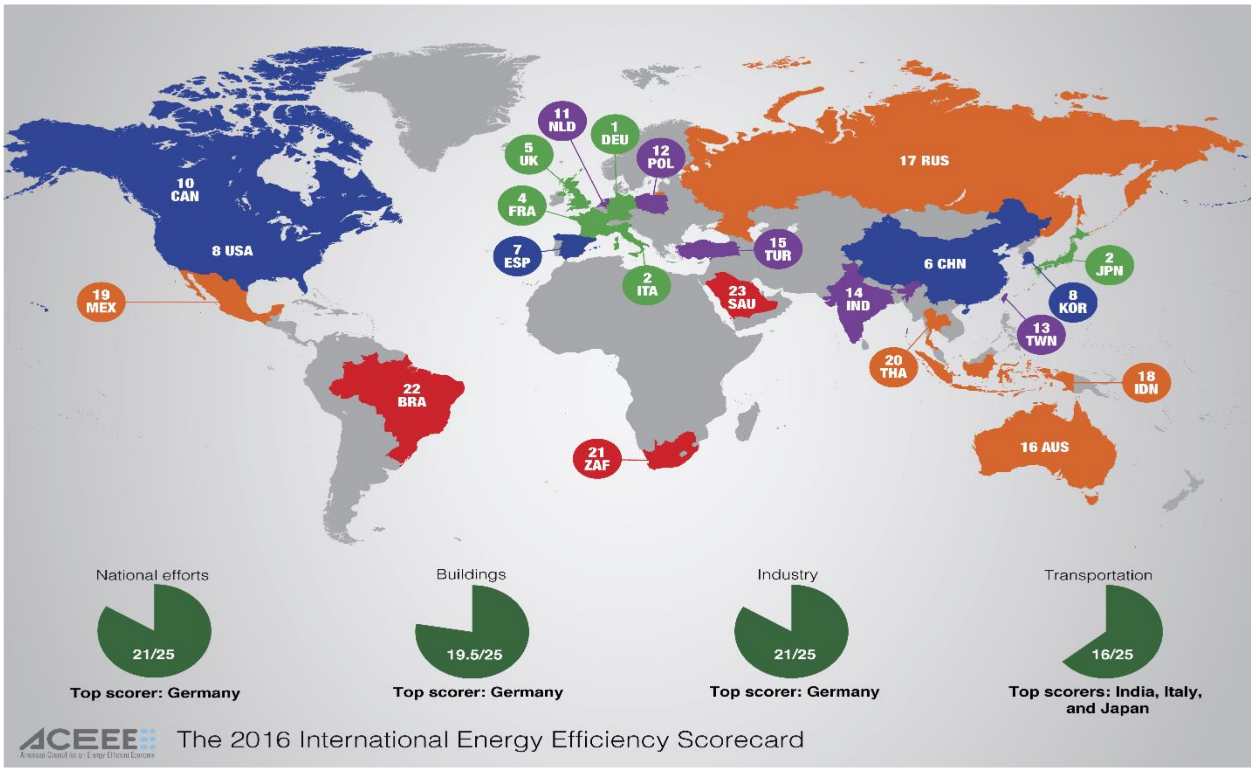


Fig. 8. Energy Efficiency Scorecard published by ACEEE, 2016. [Source: Image was retrieved from http://habitatx.com/2016/07/aceee-releases-the-2016-international-energy-efficiency-scorecard/; Note: The actual image was retrieved from the document downloaded at the same webpage.]

European Statutory Laws and Regulations on Construction of Energy Efficient Structures

In the European Union, the main legislations that covers the reduction of the energy consumption of buildings are:

- Energy Performance of Buildings Directive – 2010, with an Addendum in 2016,
- Energy Efficiency Directive – 2012. (Energy Efficiency Directive, 2012)

The Energy Performance of Buildings Directive – 2016 requires the member countries of the EU to adhere to the following guidelines: (Energy Performance of Buildings Directive, 2010)

- By 31st December of 2020, all new buildings are required to be nearly zero energy buildings,
- By 31st December of 2018, all public buildings are required to be nearly zero energy buildings,

- A minimum energy performance requirements for new buildings must be introduced while undertaking major renovations of buildings, while replacing or retrofitting of building elements like HVAC, Walls, etc,
- National financial measures are to be introduced for improving the energy efficiency of buildings.

With such effective regulations, the stress in energy efficient constructions, be it buildings or roads, researches and constructions associated with them have risen in the last few years.

Actuality of the Topic in Lithuania

The efficient use of energy resources and energy is one of Lithuania's key long-term strategic objectives in the energy sector (Ministry of Energy of the Republic of Lithuania, 2016). Lithuania, a fast growing developing economy envisions a clear goal of efficient use of Energy and adopting newer trending construction technologies to implement them. While most construction technologies have been concentrated with efficient insulation technology in the buildings, passive solar lighting and solar energy harvesting, glow in the dark roads are some of the innovative technology areas that Lithuania is yet to venture. This thesis intends to research on those areas that could be adapted in construction technology in attaining a sustainable energy efficient structures. The 3D modelling of the project is aimed to design using Virtual Reality design of the Built Environment. It could be observed that Lithuanian energy production through Renewable energy is still growing, and is yet to reach its full potential unlike other Western European countries (Fig. 9).

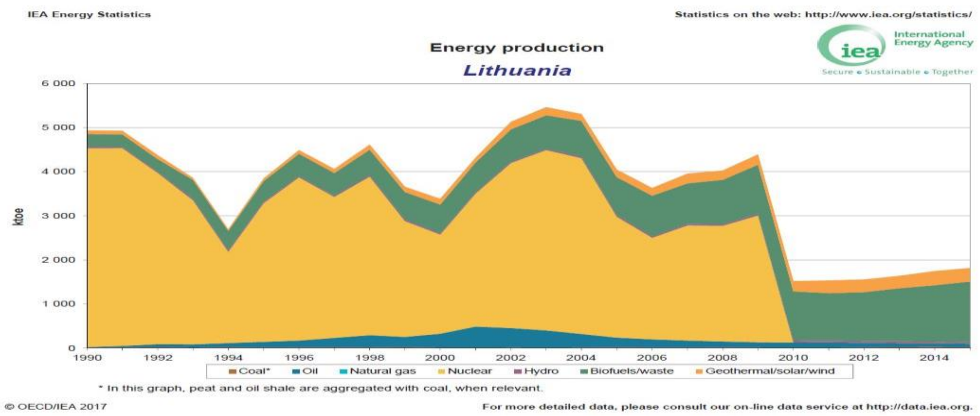


Fig. 9. Energy Production statistics in Lithuania from 1990 to 2014 [Source: Image was retrieved from a Report generated and downloaded from the link: https://www.iea.org/statistics/statisticssearch/report/?year=2015&country=Lithuania&product=RenewablesandWaste]

The production of electricity from Renewable Energy Sources in Lithuania as of 2015 is shown in Fig. 10.

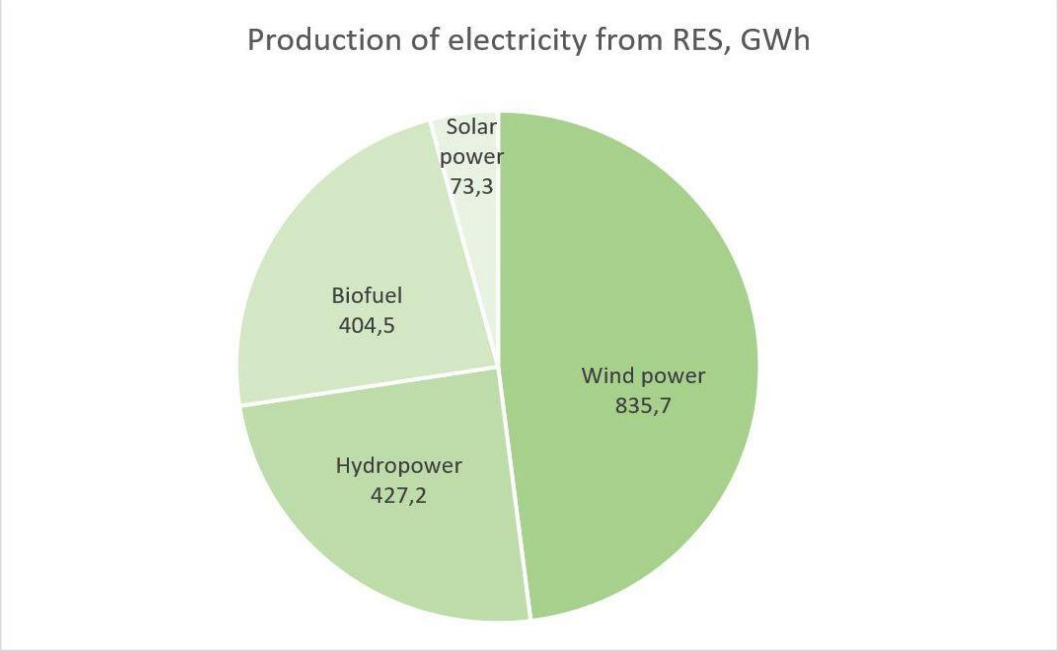


Fig. 10. Electricity from Renewable Energy Source (RES) in 2015 [Source: Lithuanian Department of Statistics, Image was retrieved from: https://enmin.lrv.lt/en/sectoral-policy/renewable-energy-sources]

While Lithuania has already met the target for 2018, it is yet to implement the EU Directive with all buildings as Energy efficient. Both Vilnius and Kaunas, the two larger cities of Lithuania boasting very high urban population, implementing new innovative energy harvesting technological constructions are very much the need of the hour. Many residential houses have already started to install Rooftop PV panels for electricity generation. However, only those connected to the Grid are calculated by the Government. There are also other researches being carried out like installing PV solar panels on moving vehicles in Kaunas.

1.2 LITERATURE REVIEW

Energy Efficient Constructions

Investing in energy efficient constructions for a sustainable future is increasing day by day around the globe. Economically speaking, betting on implementing energy efficient constructions is not only promising but offers independency from the fluctuations in the cost of energy (REHAU, n.a.). The Innovation and Networks Executive Agency of the European Commission has announced 212.5 million Euros for Renewable Energy projects (Innovation and Networks Executive Agency [INEA], 2017). With global markets predicting a great potential in zero energy structural constructions, it is high time the thesis topic is proposed in one of the fastest growing economies of the Europe and the World. Energy efficient constructions involving renewable energy harvesting structures is a new area to Construction technology. Incorporating BIM in this area has a greater scope for more innovative researches and construction practices. However, energy efficiency is not only about renewable energy harvesting but also about better insulation, passive solar lighting, etc.

With new researches in innovative materials, these are made possible and that has impacted the thesis to propose few of those innovative ideas in realizing energy efficient construction technology. Executive Agency for SMEs, another agency of the European Commission says that about 3 million construction workers working in the construction sector associated with clean energy harvesting and energy efficiency will have to update and increase their skills to meet out the new construction technology trends by 2020 (Executive Agency for SMEs [EASME], 2016). Erick O. Torres, and Gabriel A. Rincón-Mora present ideas on details about the various energy harvesting techniques that could be researched and implemented for a sustainable future in their paper (Torres & Rincón-Mora, 2005)**.** Another researcher, Faruk Yildiz compares various energy harvesting techniques and presents idea about them (Yildiz, 2009)**.** This thesis proposes an applied research on some of the effective and promising energy harvesting structures and other energy efficient constructions.

Piezoelectric Energy Harvesting

Piezoelectric energy harvesting has a lot more potential for a sustainable clean energy harvesting structure. Researchers from India, Dhananjay Kumar and Pradyumn Chaturvedi, suggests harvesting energy from floors from the vibration induced deformations of the floor tiles using piezoelectric circuits (Chaturvedi & Kumar, 2013; Kumar, Chaturvedi, & Jejurikar, 2014). While piezoelectricity is not a new concept by itself and has found practical applications in most things in day to day life, the concept of generating electricity from people walking and running vehicle vibrations is a whole new chapter of research and heated discussion. Although there has been no suggestions yet that it is a competing competitor to energy from solar photovoltaics and wind, researchers around the world have suggested that with proper research and invention of more efficient piezoelectric materials, very effective and competing clean energy harvesting structures of various kinds could be constructed.

J. Dicken et al (2012) have suggested in their research works that harvesting energy using design of special piezoelectric circuits is possible. They also offer some insight onto some of their low power applications. There has also been suggestions of using piezoelectric ceramic materials beneath the floor surface as a possible way of harvesting energy as in the case of Parul Dhingra et al (2012). Another researcher explains the technique of using piezoelectric energy harvesting for powering MEMS (Majeed, 2015). While many others have suggested similar and more innovative ways of constructing a structure that utilizes piezoelectric materials, few others have actually started to implement them in real time and test them for the efficiency. In 2014, The Cambridge Center for Smart Infrastructure and Construction had developed an energy harvester which would harvest energy from vibrations of the bridge induced by moving traffic (Cardno, 2014). In the US, a roadway near the campus of the University of California, Merced, north of Fresno, will have its pavement embedded with 2cm wide piezoelectric generators for about a distance of 60 m (Ross, 2017). However, the structure suggested in this thesis uses piezoelectric surface to generate energy from rain.

Solar Photovoltaic Panels

Photovoltaics or PVs as commonly referred to is a promising energy harvesting construction technology. The most abundant clean energy is that from the Sun itself. Solar panels is not a new area but the innovative construction designs are a great deal even for this solar energy harvesting technology. The way these are used in a structure incorporating BIM construction and other stuffs finds a place in this thesis. While the most common practice is installation of these panels on roof tops, this research work suggests using them on footpath pavements and on fibre glass geodesic dome structure, which happens to be one of the best passive solar lighting structures designed. The idea is to avoid street lighting totally, making the pathways lighted by itself from the power of sunlight. For the purpose of this thesis, a company involved with such walkable PV tiles had provided technical details about their product and gave information on their successfully installed projects (OnyxSolar, 2017)**.**

The idea behind constructing a geodesic dome is the concept of Building integrated Photovoltaics (BIPVs). Instead of installing separate solar panels, the dome’s structural tiles themselves are integrated PV tiles. However, unlike the traditional flat panel PVs, the flexible BIPVs are less efficient than their counterparts (Lowder, 2012). That said, this thesis suggests using very effective flat panel PVs at certain junctions and parts of the dome making the structure energy efficient. For the purpose of this research, an UK based company involved with construction of Geodesic domes provided details on small to large scale installation of geodesic domes for different purposes on a wide range of scale (SOLARDOME®, 2017). However, they do not use BIPVs and that was consulted from Onyxsolar. Hang-Jung Kuo et al (2016) discuss the application of BIM for verification of energy analysis of the BIPV buildings. Though their research uses BIM, another trending area of construction technology to verify the initially estimated amount of energy harvesting, applying BIM integrating Energy efficiency constructions is a very new area of research.

Another idea of utilizing PVs is by installing them as trees, that be integrated with the internet in the real time operation. Termed as "Solar trees", these unique structures are special designs that are suggested to be constructed. For the purpose of this research, an "eTree" designed and marketed by SOLOGIC, provided with details about their product. The solar tree offers multiple uses to the people like Mobile charging, Free Wi-Fi, Night Illumination, etc. (Sologic, 2017).

Wind Energy Trees

The other abundant clean energy source apart from sun is the wind itself. Constructing wind trees that bio-mimic real trees is a feasible choice for a zero energy building. Jérôme Michaud-Larivière, Inventor and CEO of NewWind points out the advantages of the trees with wind turbine leafs (Newwind, 2017). While these structures are not Building integrated like that of solar panels, these are separate elements that can harness a good amount of energy. These structures can be easily integrated into the urban landscape similar to cell phone towers, lights, electric poles and art sculptures (Meinhold, 2011). These are noiseless and provide aesthetic appeal to the surrounding. In recent years, technologies have combined in farming clean energy. There has also been conceptual ideas of piezoelectric elements integrated to generate power from wind vibrations but these are yet to be tested. As mentioned earlier, the area of research in piezoelectricity is very wide but they could be integrated or combined or designed separate to harvest energy. While most countries around the globe with abundant sea-shore have already started to invest in off-shore wind turbines, the prospectus of on-shore wind turbines or trees have equally been blooming over the recent years.

Although Lithuania has a small coastal shore with abundant artic wind, it is equally a viable choice for installation of wind energy structures inland as they are feasible and economically viable.

Glow Roads

Luminescent structures are entirely a very new area in the field with a very great scope in the future. Luminescence in structures can be achieved in two ways namely: bioluminescence and chemi-luminescence. While the former uses biological elements provide passive lighting, the later uses certain chemicals to achieve that. Constructions that are aided with this technology offer passive lighting and makes the buildings and other structures very energy efficient. However, there is no active energy harvesting in this technology but the sunlight absorption induces glow effect at night times that are so powerful that other forms of lighting can be avoided. While scientists have engineered bioluminescent indoor-plants and trees that glow in the dark, there has also been chemically induced luminescent construction materials like concrete, aggregates and paints. Both these are environmentally safe and often has been remarked as the future lighting system of human civilization where without electric lamps, the beauty of the night sky is celebrated for what it is. For the purpose of this thesis work, a Canadian company that produces glow aggregates have been contacted and details were obtained. The Company describes the product for an all-purpose decorative use and explains that these aggregates are safe for the environment (Core Glow, 2017).

A smart-highway-related concept imagined by Roosegaarde was realized though installation of glowing marking lines on Highway N329, some 60 miles southwest of Amsterdam (Wysocky, 2014). In another story, a similarly conceptualized cycle lane was constructed near Lidzbark Warminski in the north of Poland (Gould-Bourn, 2016). Singapore has been researching onto glow roads on a closed rail track (NG, 2017), while the concept maybe similar, the aim of their research remains to only aid in support of additional lighting, unlike other concepts that aim to completely avoid the electrical lightings. A European company has come with bioluminescent innovations in structures to reduce the impact of electrical lighting which covers about 19% of the global electricity consumption and 5% of the global greenhouse gas emission (glowee, 2017).

Virtual Reality 3D Modelling

Virtual Reality (hereinafter referred to as VR) 3D modelling is a new trend of construction technology, which enables the designer to practically design and construct a project on a virtual reality landscape. This augmented reality modelling and designing, often touted as the next generation of BIM has in recent years become a distinctive field of research around the world. Back in 2007, Horne & Thompson pointed out the integration of VR in the simulations of built environment like buildings, cities and landscapes (Horne & Thompson, 2008, p. 7). Howeevr, back in 2007, VR was not as sophesticated as it is today. At present, the new augmented virtual reality where the user physically interacts with the built environment is helps to study the project on real time simulations. VR fulfils "Connected BIM" concept. It supports the integration of every team member into the design process. The Augmented VR technology helps the designers to understand and analyse the improved sense of scale and spatial relationships, which is useful in near real-time feedback. It is a significant construction technology that can be used to accelerate design decisions by integrating more stakeholders in the validation of design concepts at full-scale (Herridge, 2017).

Augmented VR not only takes the designer to the construction site but also enables to simulate the environments and study the weather pattern of the construction site. For an Energy harvesting construction project, such virtual world simulations helps to better plan, design and construct in a real time built environment.

Revit, a software product of Autodesk which is known for its BIM application has now incorporated VR under a new software called the Revit Live. Although there are other plugins available to use VR in Revit itself, this new software enables the user to integrate BIM with VR. VR experience is achieved through a VR Headset. However, the physical motor experience can be experienced just by using Stand-alone VR Headsets, VR Headsets with Haptics, VR Headsets with Mounts, VR Headsets with Joysticks and touchpads (Kraft, 2017).

1.3 AIM AND OBJECTIVES

The aim of the Final Master Degree Project is to research the innovative energy harvesting technologies and their application in the built environment.

The main research objectives of this project are:

- Discuss the recent trends in innovative energy harvesting technologies, their present scenario in various countries and review literature supporting the various energy harvesting technologies,
- Outline the proposed energy harvesting structures, their construction and installation practices and their energy calculation methodology,
- Outline the Virtual Reality design methodology,
- Applying the research work in Nemunas River Island Park through Landscape architecture, by proposing three layouts of the energy harvesting structures' location on the landscape, by calculating their total energy production, by designing a landscape 3D model and by a making a Construction Project Scheduling with Cost Estimation analysis.

2. METHODOLOGY

This Chapter covers the methodology of the scientific research carried and the proposals in detail. The description of the various innovative energy harvesting and energy efficient structures are outlined. Following that, the energy calculations methodology and the 3D modelling design methodology incorporating Virtual Reality is explained. Common construction practices of the different innovative energy harvesting are briefed at the end.

2.1 PROPOSED ENERGY HARVESTING STRUCTURES

The different energy harvesting structures proposed around the Science museum in the Science Island are as follows,

1) Photovoltaic Geodesic Dome
2) Photovoltaic Floor
3) Photovoltaic Trees
4) Wind Energy Trees
5) Piezoelectric Rain Farm
6) Luminescent road

The methodology of planning these structures involve designing three different alternate plan layouts which is carried out using Photoshop tools on Google satellite maps. Each of the above structures are marketed by individual firms. The details of each of these with their manufacturer details are briefly report in the following pages.

1) Photovoltaic Geodesic Dome

   The PV Geodesic Dome will be the main structure of interest outside the main Science museum in the Science Island museum park (Similar to Fig. 11, 12). The dome is proposed as a structure that shall have permanent exhibition of the PV Energy Technologies, their future for sustainable energy harvesting, etc. The diameter of the dome is planned to be 10 m in size. Building Integrated Photovoltaic Crystalline Silica panels are installed on the exterior of the Dome. The whole dome will power itself inside and the extra-energy harvested will be sent to the grid. The solar dome aims to promote the energy and social values of harvesting solar energy. (SOLARDOME®, 2017)The geodesic Glass domes of permanent structures are built by *SOLARDOME®* under the name "*SOLARDOME® PRO*" (SOLARDOME®, 2017). The model chosen for this Thesis is "*SOLARDOME® Paradise*" (SOLARDOME®, 2017).

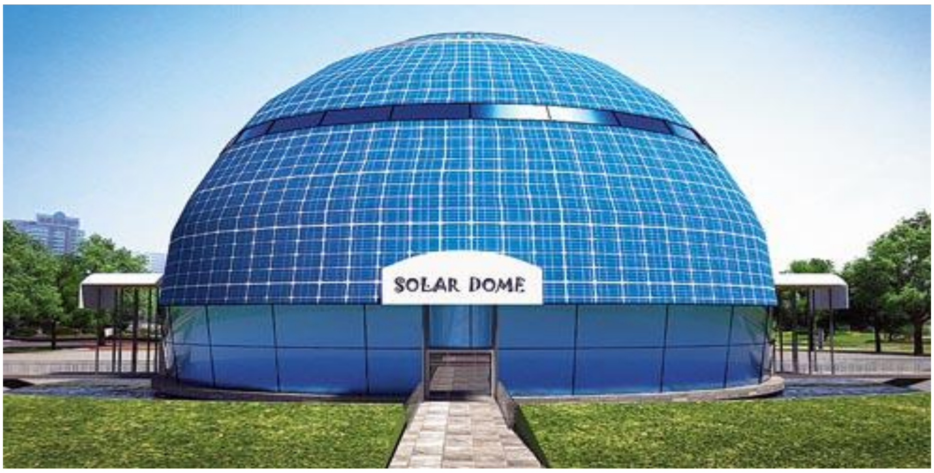


Fig. 11. A Solar Dome in India [Source: Image Retrieved from https://www.telegraphindia.com/1170224/jsp/saltlake/story_137353.jsp]

Fig. 12. SOLARDOME® PRO science lab, Watford Grammar School for Girls [Source: Image Retrieved from http://www.solardome.co.uk/gallery/solardome-pro/]

2) Photovoltaic Floor

The PV floor panels are designed as walkable floor which is proposed as one of the structures to be installed on one of the pathways leading to the Science Island museum (Fig. 13). The PV floor uses the solar light to generate electricity which is connected to the Grid. The proposed distance of the PV floor is 100 m with a pavement width of 3 m. This again promotes the use of solar energy harvesting using photovoltaic technology. The Photovoltaic or PV panels are designed as by **Onyxsolar** (OnyxSolar, 2017)**.** These floors use the solar light and generate electricity that shall be used to light the lamps along the pathways.

Fig. 13. Walkable Photovoltaic Floor by Onyxsolar [Source: Image Retrieved from http://www.onyxsolar.com/walkable-photovoltaic-roof.html]

3) Photovoltaic Trees

The PV Trees are tree like structures with solar panels (Fig. 14). This shall be one of the architectural elements of the landscape architecture of the Science Island museum park area. The total number of trees proposed are 10. Each tree is 3 m tall and has four PV panels installed. Each tree is fitted with LED lights that illuminate at night. The suggested model uses a self-storage battery, details of which was not provided by the Manufacturer. However, all trees might be connected to the Grid since the energy production varies throughout the year. During the daytime, they only stand as a part of the landscaping architectural elements. The various services provided by the PV tree includes the following (Sologic, 2017):

a. Shaded resting area;
b. Free Wi-Fi;
c. Docking stations for smart phones and other electric devices;
d. Illumination by night.

The proposed form of *etree* is marketed by "**Sologic** – Renewable Energy Systems", a company based in Israel.

High end models could provide additional services like: (Sologic, 2017)

a. Interactive LCD display (an ideal platform for communicating information to the community)
b. A water cooler with fresh running drinking water
c. Trough for pets.

Fig. 14. 3D Graphical model of PV eTree [Source: Image Retrieved from http://sol-logic.com/etree/]

4) Wind Energy Trees

Wind Energy trees mimics the resemblance of a tree with leaves, only the leaves will be rotating wind turbines (Fig. 15, 16). These wind energy harvesting trees are designed and marketed by ***NewWind*** under the name *WindTree*® (Newwind, 2017). The total number of trees proposed are 10. These tree also shall be a part of the landscaping architectural element of the Science Island Park. Each tree has 54 - 63 leaf-turbines and the design capacity is 4.1 kW.

A total of 54 leaf-turbines can capture up to 5.4 kilowatts of energy at a time and produce around 2,400 kWh annually (Schreiber, 2016) with an activation threshold of 1.3 m/s and power generation from a minimum wind speed of 2 m/s (Fig. 18) (Newwind, 2017). See Fig. 17, 19 for specifications details and energy production.

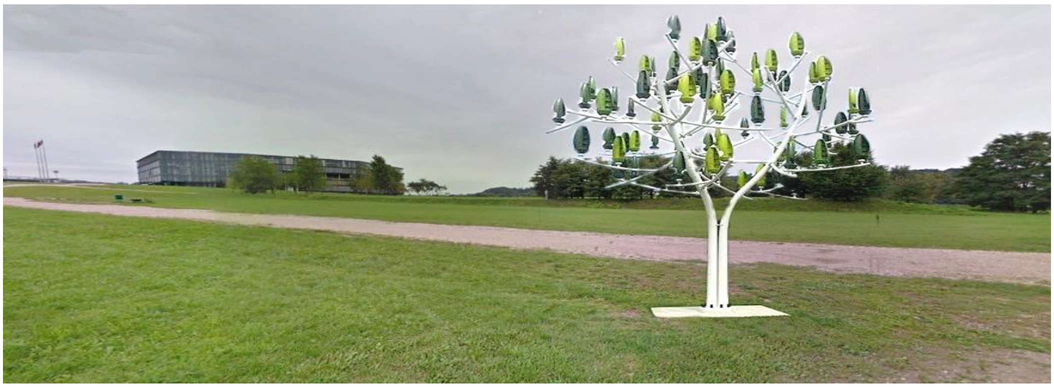


Fig. 15. Photo-shopped image of Wind Tree in Science Island Park [Sources: Google Street View shot],

Fig. 16. Aero-leaf Wind Turbine [Source: newwind, 2017]

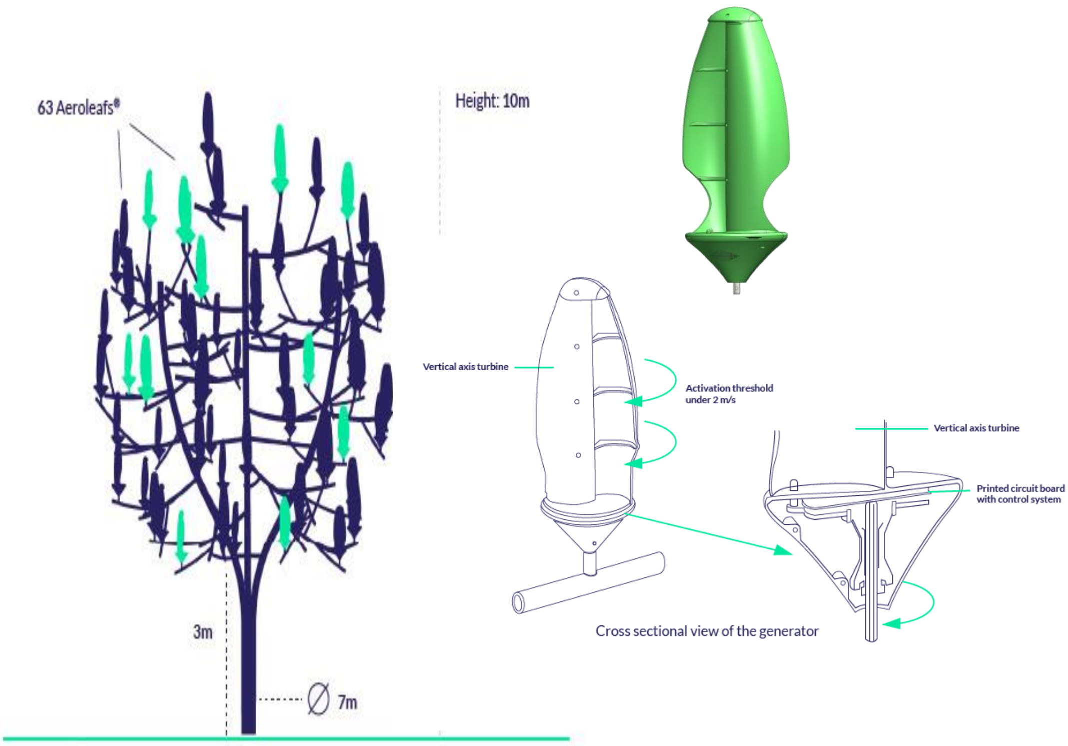


Fig. 17. Image of the Model Wind tree with working of Aeroleaf® [Source: newwind, 2017]

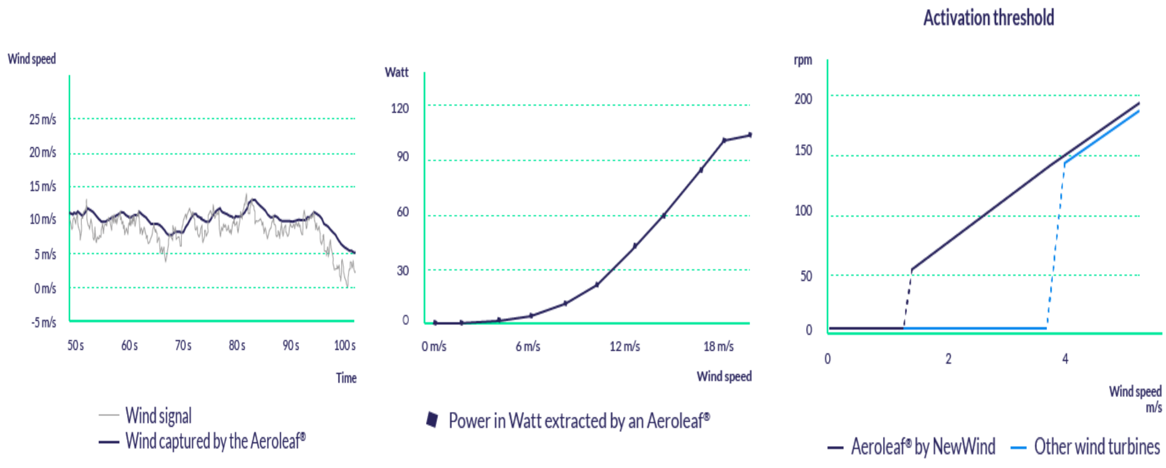


Fig. 18. Energy Production details by WindTree® [Source: newwind, 2017]

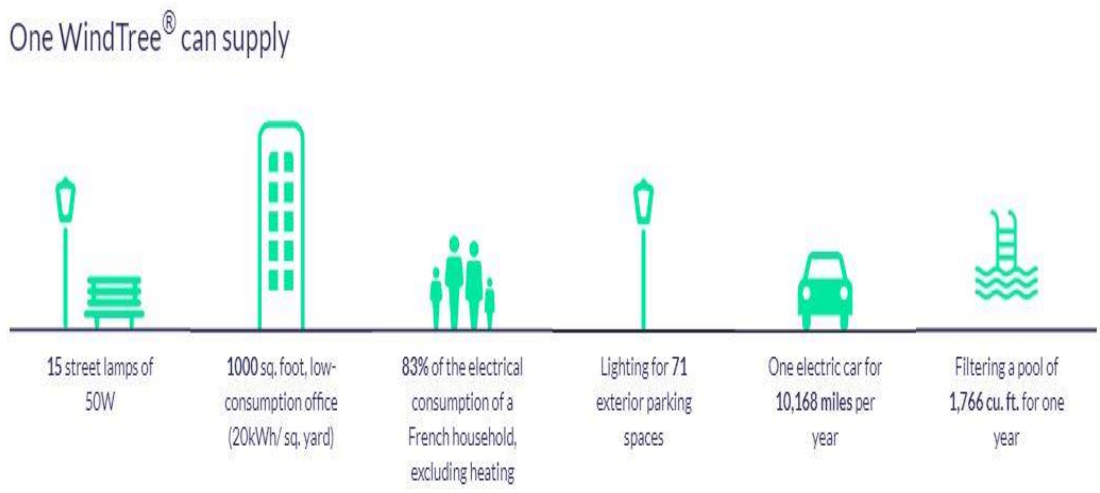


Fig. 19. WindTree® Energy Supply Equivalence Details [Source: newwind, 2017]

5) Luminescent Road

The proposed concrete pavement road will be 500 m long with a pavement width of 3 m. It will be the main road leading to the Solar Dome. Safe luminescent aggregates are used on the road surface. These aggregates are not bio-synthesized but are chemically made. These aggregates make the road to glow at dark, thereby the road becomes a self-lighting pathway for the public during the night time (Fig. 20). This promotes the current research on Bio-luminescent lighting and the values of their practical applications in the future (Glowee, 2017). The road is designed only for pedestrian walking and not for heavy vehicles.

Fig. 20. Luminescent Aggregate Concrete Road [Sources: Core Glow Product Gallery, Retrieved from http://www.coregravel.ca/products/core-glow/]

6) Piezoelectric Rain Farm

This is a separate farm where special structures are installed to harvest energy from rain. Since rain is not a viable source throughout the year, the new design proposes partly using solar panels on them. The structure is also redesigned to represent bio-mimic incorporated with the Architecture. The original conceptual design of the piezoelectric rain farm was made by Designer Anthony DiMari (Fig. 21.), which does not include the Solar panels equipped. In theory, these structures are covered by piezoelectric elements on the outer side. The rainfall induces the application of mechanical loading on these elements and thereby producing electricity as a result of the piezoelectric effect. However, the electricity produced is intended for fun lighting for the children to play, since the energy production would be minimal. The Farm will be installed as a monument itself, like that of the solar dome in a separate part of the Science Island Park.

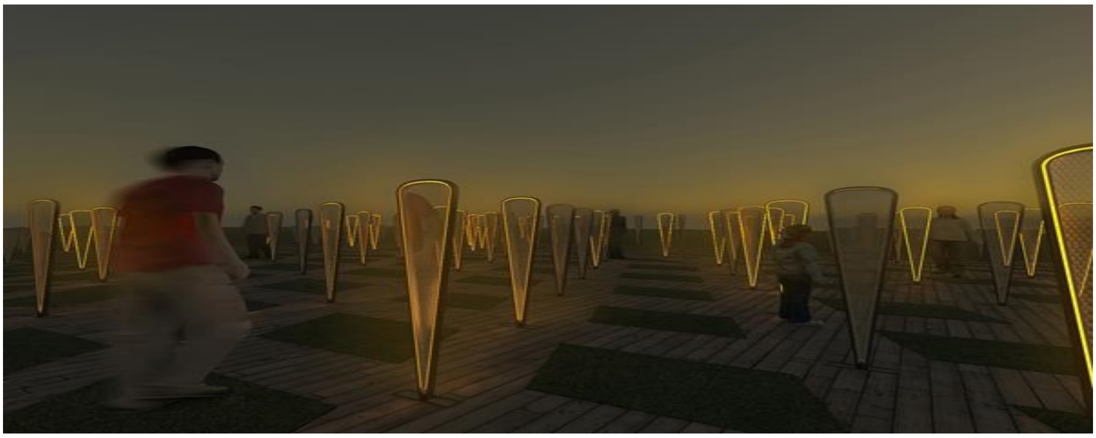


Fig. 21. Imagined Urban Field by Designer Anthony DiMari (Actual design intended for Wind Energy), [Source: Image retrieved from http://anthonydimari.com/]

2.2 FORMS OF INSTALLATION AND CONSTRUCTION PRACTICES IN THE BUILT ENVIRONMENT

The different forms of installation of each innovative energy harvesting technology that could be applied to the Built environment are discussed.

1) Photovoltaic Technology

   Photovoltaic panels are basically installed in two ways:

   - Stand-alone Installation
     - Roof-top Installation,
     - Ground Mounted PV Arrays,
     - Ground Mounted PV Trees,
     - PV Floors
   - Building Integrated Photovoltaics
     - PV Roofs,
     - PV Walls,
     - PV Windows,
     - PV Floors,

   The difference basically is the type of material used in the PV panels. While the stand-alone Photovoltaics are usually Polycrystalline material, the BIPVs are mostly Thin Film Technology. Polycrystalline PV panels generate more power than the Thin Film PV panels.

2) Wind Turbine Technology

   Wind Turbines are traditionally installed as Wind mills on rural locations over either hill sides or on the sea-shore. In recent years, offshore wind turbine installation are also being implemented. With new research and designs, micro and nana-structured turbines have been innovated. With such smaller turbines, new innovative forms of wind energy harvesting structures have been made possible. The small-scale wind turbines are usually integrated as trees. These trees can be installed on the Ground, Roof-tops, etc. It should be observed that the fan blades are usually perpendicular to the ground in most cases. However, fan blades perpendicular to the ground surface are also marketed (See Fig. 17). There are also patent awaiting designs which use Walls for installation (Fig. 22).

Fig. 22. Modular Architectural Wind Micro-turbines [Source: Photo retrieved from https://www.treehugger.com/sustainable-product-design/urban-modular-architectural-wind-power-microturbines.html]

3) Piezoelectric Technology

   Piezoelectric technology hasn't achieved its pinnacle yet but tedious research are being done to make it effective, in par excellence to other Renewable energy harvesting technologies. The common forms of installation is always as a walkable floor, where in the people's walking induces mechanical load for electricity generation. In recent years, these are also implemented on Roads for Research purposes.

The construction practices of each of the innovative energy harvesting structures are discussed in the following pages.

a) Photovoltaic Constructions

   Construction techniques will vary depending upon the type of piezoelectric constructions. The common practices are listed for each of the element, however some elements are exclusively patented by some companies that require skilled labour for the construction.

   ❖ PV Geodesic Dome (Non-Concrete types)

     Common technique practiced for construction of substructure:

     - Initially clearing and leveling the site is carried out. For further levelling of the surface, a sand layer may be used and provide a base for the foundation slab.
     - The weight of the entire dome is spread evenly throughout the entire structure so that the dome only needs support around its base, leaving lots of room inside. The edges of the dome rests on a foundation of underground concrete wall around the perimeter of the structure.

- A trench is dug for the foundation footing. The base of the dome is not circular; rather, it is outlined by five short walls alternating with five long walls (twice the length of the short walls).
- Forms are placed for the footings; many builders like to use permanent Styrofoam forms that need not be removed. Concrete is then poured in the footing forms.
- Reinforcing steel bars are tied together in a grid, and concrete is poured to form the foundation.
- Foundation walls are built atop the footings, up to approximately ground level.
- Floor joists are installed by standing wooden 2x12, 16 in (40 cm) apart above the foundation. The joists are nailed to a perimeter wooden frame and a wooden crossbeam. Three-quarter-inch (1.9-cm) thick plywood sheets are laid across the joists and nailed in place.
- The interior ground surface is lined with paver blocks.

Different techniques commonly practiced for construction of superstructure:

- Space frame

  Building domes using space frame is actually quite simple, the struts are made from solid bar and they are connected together with solid balls that have fixing points machined into them. See Fig. 23.

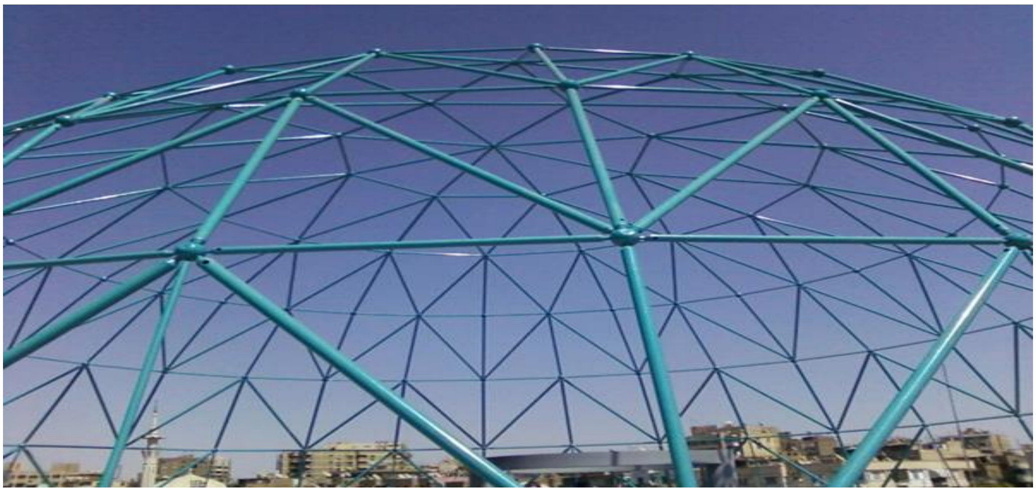
  

  Fig. 23. Space Frame Dome Structure [Source: Photo retrieved from http://www.spacebuildersegypt.com/gallery/15l.jpg]

- Stressed skin

  Metal or fiberglass panels are bolted/riveted together to form the dome, there are no beams, hubs or separate support structure the skin does everything. See Fig. 24.

Fig. 24. Stressed Skin Dome Structure [Source: Photo retrieved from http://geo-dome.co.uk/article.asp?uname=mydome]

- Flattened conduit

Probably the simplest way to build a geodesic dome frame, all that needs to be done is flatten the end of some metal tubing bend it slightly then drill a hole. See Fig. 25.

Fig. 25. Flattened Conduit Dome Structure in Sierra Nevada, Spain [Source: Photo retrieved from http://www.xcube-engineering.com/projects/glamping.html]

- Tube and hub

  Instead of joining the struts directly together, a larger diameter pipe is used as a hub holes are drilled through the hub and the struts are bolted to it. See in Fig. 26.

Fig. 26. Tube and Hub Jointed Dome Structure [Source: Photo retrieved from https://www.ziptiedomes.com/geodesic-shelter-domes/index.htm]

- Beam and hub

  Wooden beams are attached to specially made hubs to form the dome framework; the angles are taken care of by the hubs. See in Fig.27.

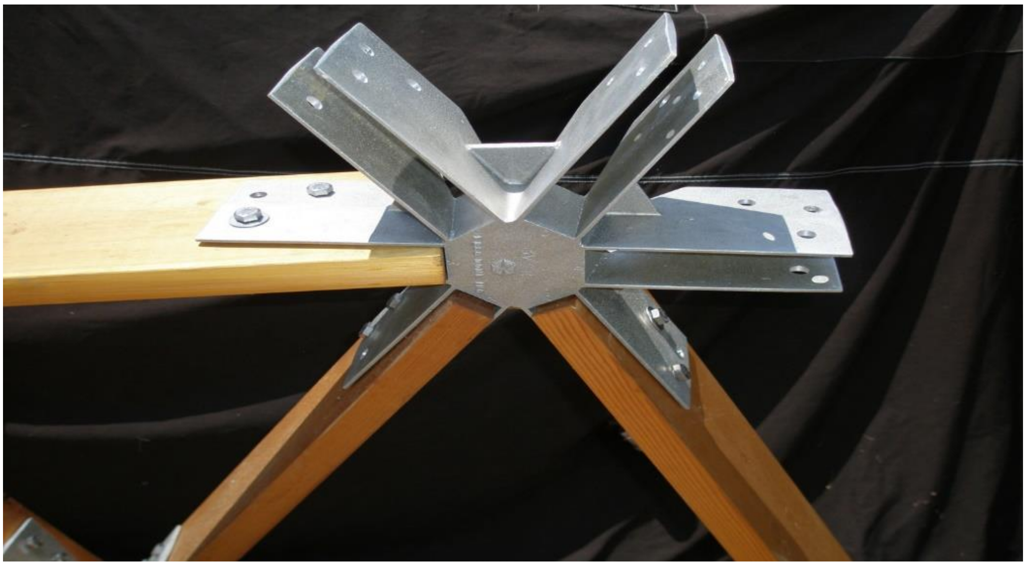


Fig. 27. Beam and Hub Joints [Source: First Photo retrieved from http://www.domeincorporated.com/hub-connectors.html; Second Photo retrieved from http://www.domeincorporated.com/hub-connectors.html]

- Panellised timber frame

  This system uses wooden beams but instead of metal hubs at the joints panels are made that join at the edges and have the outside material attached (usually plywood). These panels are factory made so all you have to do is nail them together in the correct order to build a dome.

❖ PV Floor

Since PV floors are a patented product of Onyxsolar, the installation technique practiced is unique and is only carried out by Onyxsolar.

❖ PV Trees

Common technique practiced for construction of substructure:

- Initially clearing and leveling the site is carried out. For further levelling of the surface, a sand layer may be used and provide a base for the foundation slab.
- A trench is dug for the foundation footing.
- Forms are placed for the footings; many builders like to use permanent Styrofoam forms that need not be removed. Concrete is then poured in the footing forms.
- Reinforcing steel bars are tied together in a grid, and concrete is poured to form the foundation.

However, PV trees use the same Ground-based mounting supports that include:

- Pole mounts, which are driven directly into the ground or embedded in concrete.
- Foundation mounts, such as concrete slabs or poured footings
- Ballasted footing mounts, such as concrete or steel bases that use weight to secure the solar module system in position and do not require ground penetration. This type of mounting system is well suited for sites where excavation is not possible such as capped landfills and simplifies decommissioning or relocation of solar module systems.

PV Panel installation depends on

- The tilt angle of the panel

  This depends on the location and time of the year. As a rule of thumb, solar panels should be more vertical during winter to gain most of the low winter sun, and more tilted during summer to maximize the output (Dricus, 2015).

- The General Method

  The optimum tilt angle is calculated by adding 15 degrees to latitude during winter, and subtracting 15 degrees from latitude during summer.

- The Effective Method

  This is an improvement of the general method that gives better results.

  For winter, the optimum tilt angle for solar panels is calculated by multiplying the latitude by 0.9 and then adding 29°. This angle is steeper than the general method but very effective at tapping the midday sun which is the hottest in the short winter days.

  For summer, the tilt angle is calculated by multiplying the latitude by 0.9 and subtracting 23.5°.

  For spring and fall, the optimum tilt angle is calculated by subtracting 2.5 from the latitude.

The tilt angles are also more effectively calculated through online software that incorporate google maps into them.

- The orientation of the solar tree

  The direction towards which the solar panel is tilted,

- The tracking of sunlight.
  - No tracking or Fixed,
  - Single Axis Tracking,
  - Dual Axis Tracking

b) Wind Trees

Common technique practiced for construction of substructure:

- Initially clearing and leveling the site is carried out. For further levelling of the surface, a sand layer may be used and provide a base for the foundation slab.
- A trench is dug for the foundation footing.
- Forms are placed for the footings; many builders like to use permanent Styrofoam forms that need not be removed. Concrete is then poured in the footing forms.
- Reinforcing steel bars are tied together in a grid, and concrete is poured to form the foundation.

The superstructure which is the wind tree is bolted on to the slab and erected. However, Wind tree, being a patented product might follow a unique installation technique.

c) Luminescent Road

The luminescent road construction may be possible with the traditional road laying procedure but using a Concrete paver machine is recommended. However, Asphalt installation is also possible but with manual working of the surface. Whatever method is used for pouring the concrete onto the road, skilled laboring is very much required to sow the glowing aggregates. Once the stones or pebbles are embedded, the concrete or asphalt road surface is smoothed and compacted (See Fig. 28). Paver stone embedded with glow stones are other forms of installation (Fig. 29, 30).

Fig. 28. Glow stones manual installation on Asphalt Road [Source: Photo retrieved from http://www.imagine7.co.uk/glowstones/]

Fig. 29. Paver tiles embedded with Glow [Source: Photo retrieved from http://www.dudeiwantthat.com/outdoors/garden/glow-stones.asp]

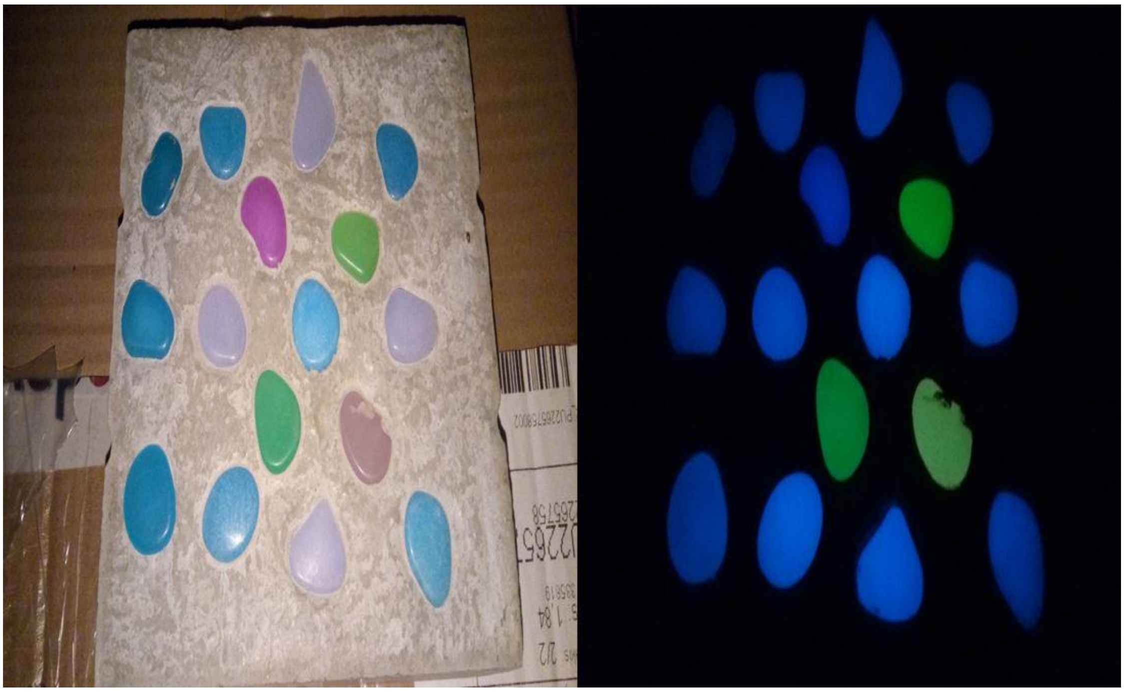


Fig. 30. Paver tiles embedded with Glow stones [Source: Photo taken by the Author]

d) Piezoelectric Rain farm

Since the structure is a conceptual proposal, structure itself needs to be designed with: solar PV panels, LED lightings embedded along with the piezoelectric ceramic surface.

The conceptual idea is to bio-mimic a mushroom. The combination of piezoelectric ceramics and PVs for energy harvesting is achieved by special circuit designs. Supercapacitors and normal lithium-ion rechargeable batteries are sufficient for storage of the harvested energy.

However, since this is a new area, there has been neither standard set of energy calculation methodology nor a perfect PZT ceramic material that is very efficient to harvest the energy. That said, since PVs are combined, normal inverters are good choice for storing the energy generated. It should be observed that the PV panels are embedded and won't be able to tilt or orient in a particular direction.

2.3 ENERGY CALCULATIONS METHODOLOGY

Photovoltaic Energy Calculation

For a PV panel, the energy comes as waves of Photons from the Sun. The light energy is converted into electrical energy. The total power P_{IN} per area for a given Photon spectrum $\Phi_0(\lambda)$ is given by the formula in Eq.1. (Fonash, 2010):

$$P_{IN} = \int_{\lambda}^{0} \frac{hc}{\lambda} \Phi_0(\lambda) d\lambda \qquad (1)$$

The methodology for calculating PV Energy output for PV panels involves collecting data on the following:

- Solar irradiance;
- Tilt of the installation;
- Direction of the installation.

For a tilted PV panel, the radiation calculation takes into account three components namely: Direct radiation, Diffuse radiation, Reflected radiation. The overall radiation E_{Gen} is given by the formula shown in Eq.2 (Mertens, 2014):

$$E_{Gen} = E_{Direct\_Gen} + E_{Diffuse\_Gen} + E_{Refl\_Gen} \quad (2)$$

Where:

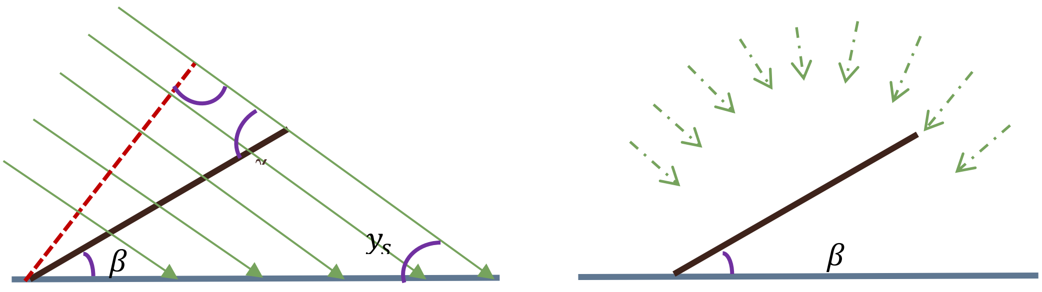
$$E_{Direct\_Gen} = E_{Direct\_H} \cdot \frac{\sin(y_s+\beta)}{\sin y_s} \quad (2.1)$$

$$E_{Diffus\_Gen} = E_{Diffus\_H} \cdot \frac{1}{2} \cdot \cos(1+\beta) \quad (2.2)$$

$$E_{Refl\_Gen} = E_G \cdot \frac{1}{2} \cdot \cos(1+\beta) . ALB \quad (2.3)$$

E_{Direct_H} : Direct Radiation on horizontal surface; E_{Diffus_H} : Diffuse Radiation on horizontal surface; E_G : Reflected Radiation on horizontal surface; y_s : Solar altitude angle; β : Elevation angle of Solar Generator; ALB : Albedo Value.

Usually, for the Solar Radiation calculation, Direct Radiation and Diffuse Radiation are used as they are anisotropic (Fig. 31.a, 31.b). Reflected Radiation is usually not considered as it is isotropic.



(31.a) **(31.b)**

Fig. 31: (a) Direct Radiation on Tilted Surface [Sources: Image based on picture from *(Mertens, 2014, p. 34)*]; **(b)** Diffuse Radiation on Tilted Surface [Sources: Image based on picture from *(Mertens, 2014, p. 36)*].

The formula for calculating the Energy of the Photovoltaic panel as given in Eq.3 (Šúri, Huld, Dunlop, Albuisson, & L., 2006):

$$E = 365 * P_k * r_p * H_{h,i} \quad (3)$$

Where: E - energy (kWh/an); P_k (kW) is the peak power installed; r_p is the system performance ratio; $H_{h,i}$ is the monthly or yearly average of daily global irradiation on the horizontal or inclined surface (1025 kWh/m^2 in Kaunas on horizontal surface) (Lietuvos Energetikos Institutas, 2010)

Wind Energy Calculation

The methodology of the calculation of the wind power with respect to rate of change of energy, involves the formula as given in Eq.4. (The Engineering ToolBox, 2017)

$$P = \frac{\rho A v^3}{2} = \frac{\rho \pi d^2 v^3}{8} \quad (4)$$

Where: P - power (W); ρ - density of air (kg/m^3); A - wind mill area perpendicular to the wind (m^2); v - wind velocity (m/s); π - 3.14....; d - wind mill diameter (m).

For any design of wind turbine, the theoretical maximum power efficiency is 0.59 which is the Power coefficient given, C_{Pmax} (The Royal Academy of Engineering). However, no wind turbine can operate at the maximum power. C_P ranges from 0.35-0.45. Therefore, the actual wind power is calculated by the formula as shown in Eq.5.

$$P = \frac{\rho A v^3 Cp}{2} \quad (5)$$

It should be noted that the air density lowers with temperature and altitude. Having said that, the major factor for production of wind power is the velocity of wind. 20% increase in wind velocity will increase the power generation by 73% (The Engineering ToolBox, 2017).

2.4 3D VIRTUAL REALITY DESIGN METHODOLOGY

The Virtual Reality (VR) designing is pretty much Revit 3D modelling of the project but with Graphical rendering and conversion to VR Headset friendly file for the virtual reality experience. The following software were used:

- Revit 2015,
- Revit Live (Trial Version),
- Sketchup Pro,
- Lumion 4.5.1 (Graphic Rendering software),
- Wondershare Video Converter Ultimate

The hardware used were,

- A computer,
- ANT VR Headset (Fig. 32),
- Lenovo A7010a48 Mobile

Fig. 32. ANT VR Headset [Source: Photo taken by the Author]

The designing procedure of VR modelling is as follows:

- Initially, the site location is traced from Google Earth into the Sketch-up Pro;
- The Google earth data traced is set to topography of the real time ground surface and is saved as an AutoCAD file;
- The models of each of the energy harvesting element is designed in Revit separately in the meantime;
- The site location as AutoCAD file is either linked or imported into Revit for site modelling;
- Once the site location is linked to the Revit, the topography is modelled using the existing contour data from the Google earth;
- Upon site modelling, each of the energy harvesting element is placed for a rough non rendered version of the design;
- The final Graphics are rendered using Lumion Graphics Engine and a motion walkthrough video is saved;
- This video is again rendered and converted into 3D SBS VR video using Wondershare Video Converter Ultimate.

3. APPLICATION OF THE RESEARCH WORK AS BUILT ENVIRONMENT IN NEMUNAS RIVER ISLAND, KAUNAS

Kaunas is the second largest city in Lithuania. Once the capital itself, the city with its very old cultural heritage also boasts with very modern constructions. With a large population of the International student community and extravagant life, the city council has proposed for the construction of a Science Museum in the Island besides the Žalgiris Arena in Kaunas city. With the project itself a monumental work, the area surrounding the museum which is a green park has more usefulness with the new plans of the Science Island.

Three plans are proposed and the energy calculations of each of the different energy harvesting structures are calculated. The 3D design models and Cost estimation details are also presented.

3.1 SITE LOCATION

The location of the proposed Science Island museum lies in the island of the Nemunas River that flows in Kaunas. The whole area of the island is approximately 234,624 m^2 (Fig. 33). This calculation is based on the area calculation through GPS satellite tracking by Google Maps and the accuracy of the total land area of the park should be tested in the next stage of project development through Surveying. It should be noted that the area of the park excludes the part of Island with the Žalgiris Sports and Entertainment Arena.

Fig. 33. Map showing the location of Science Island park area enclosed with lines connecting circles [Source: Google Maps]

3.2 PROPOSED LAYOUTS

The reason as to why different layouts of the installation of energy harvesting structure are requires are as follows:

- The choice of better aesthetic appeal,
- Public exploration of the project area,
- Spreading distance of each structure with respect to the Main building.

The layouts were designed on google maps as a base layout (Fig. 34, 35, 36). Among three different alternative layouts of the energy harvesting elements, the third layout [see Fig. 36 in p. 41] is chosen based on the following criteria,

i. Aesthetic Appeal

Since the proposed project involves Landscape architecture, the third layout utilises different architectural aesthetic principles such as Order, Repetition, Spacing, Proportions in the placing of these structures throughout the Science Island Park.

ii. Extensive Utilisation

The Science Island park area is used from one corner of the island to the other corner fully, with the PV Geodesic dome and Piezo-rain farm placed at the opposite ends of the Park. The location of these elements thus make the park fully exploited for the public to walk around.

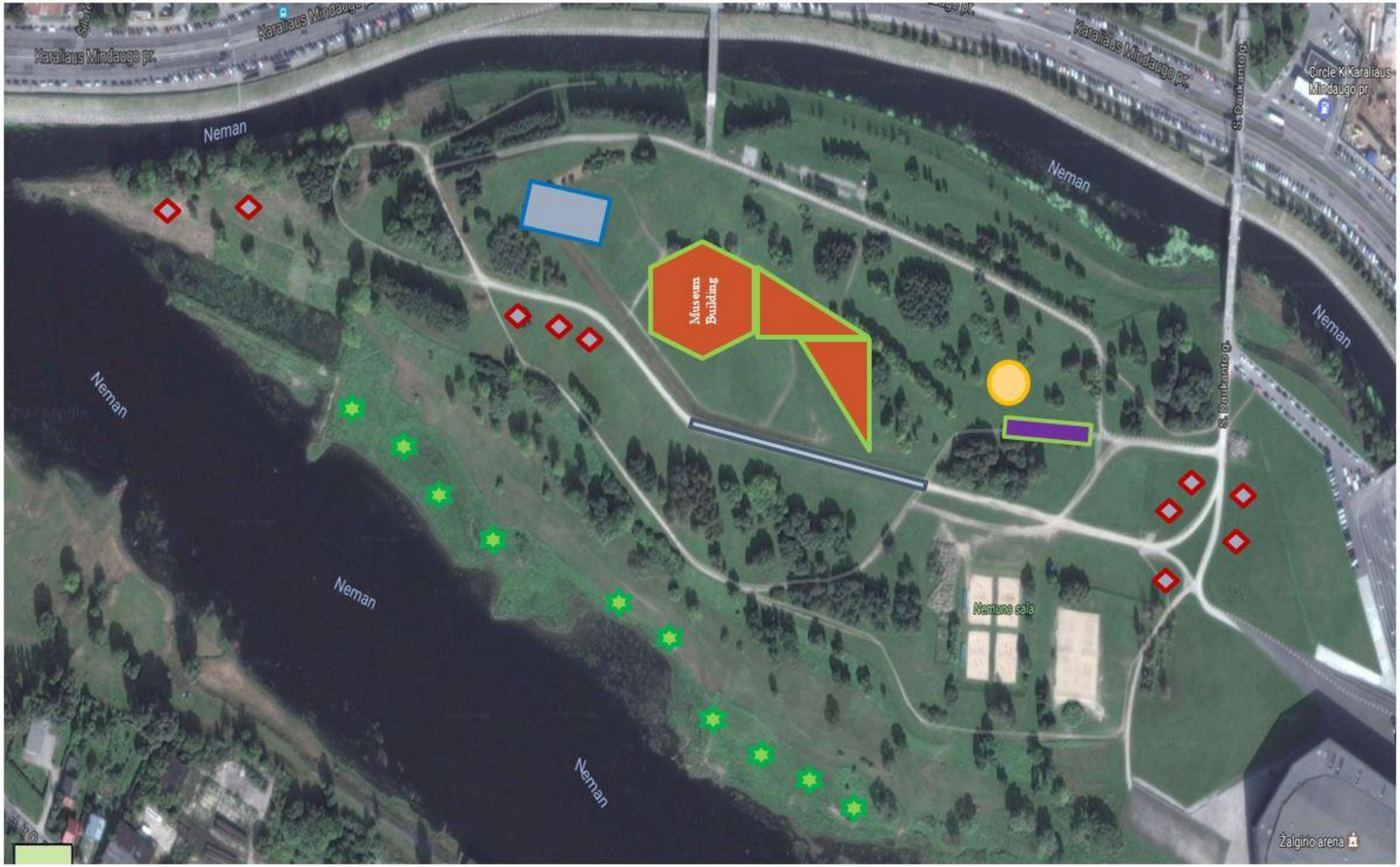


Fig. 34. Layout 1 of the proposed Energy harvesting structures and Landscape Architectural Elements [Source: Google Maps Satellite view]

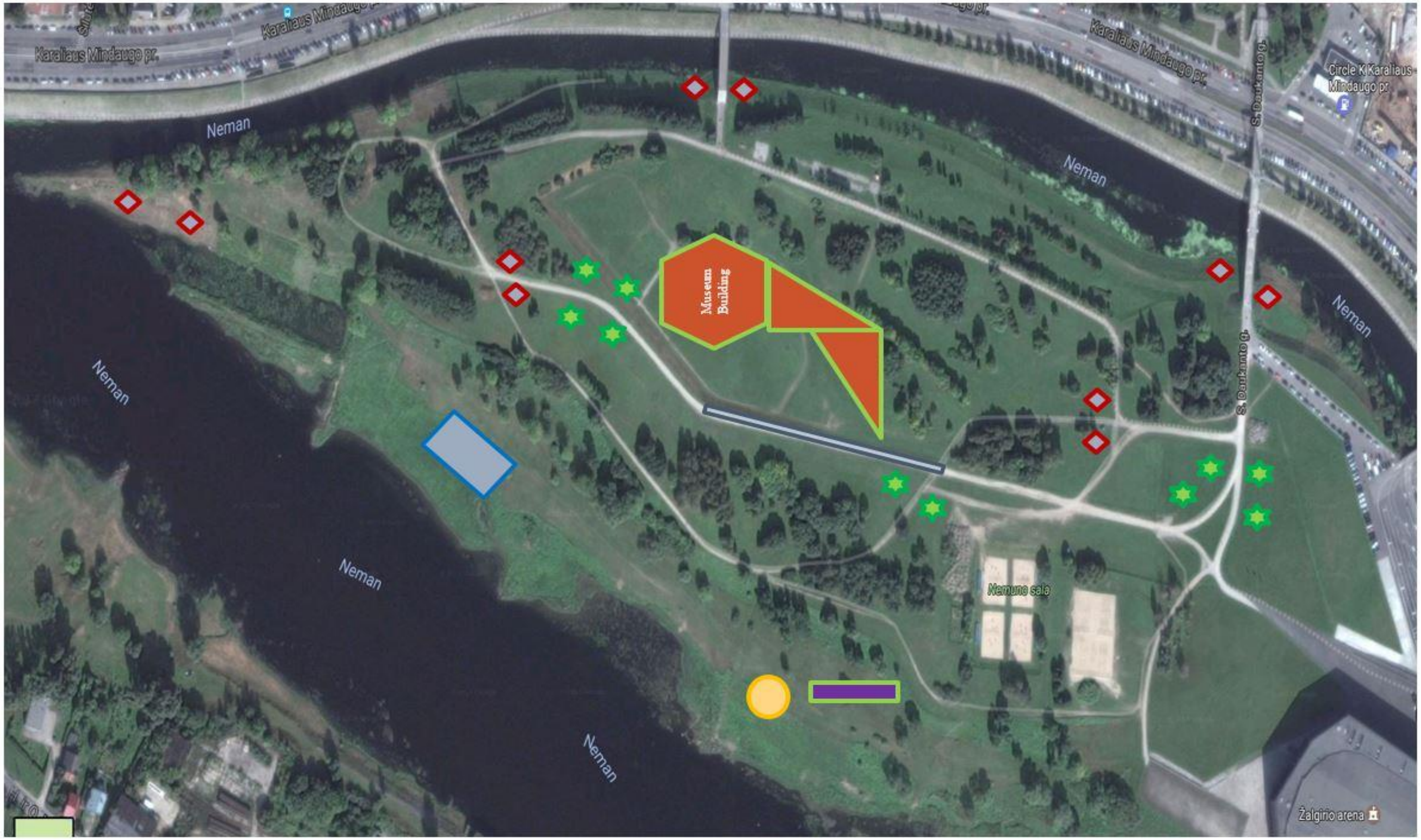


Fig. 35. Layout 2 of the proposed Energy harvesting structures and Landscape Architectural Elements [Source: Google Maps Satellite view]

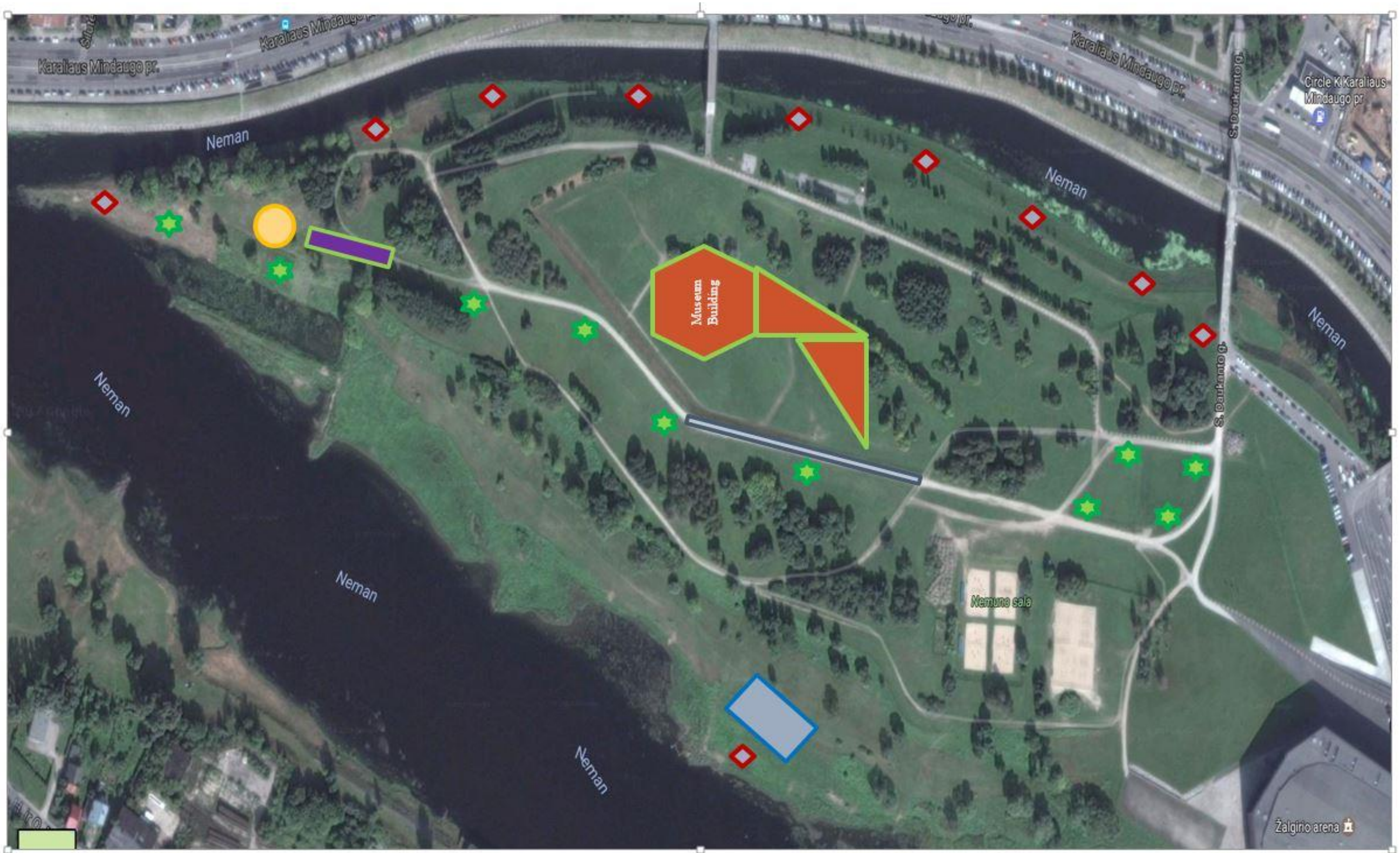


Fig. 36. Proposed Layout type 3- Science Island Park [Source: Google Maps Satellite view]

Table 1 – Description of Labels in the layouts [From p. 39, 40, 41]

Sl. No	Technology	Element	Description	Quantity	Size
1.1	Photovoltaics		PV Geodesic Dome	1	Diameter 10 m; Height 5 m
1.2			PV Trees	10	Height 4.5 m
1.3			PV Floor	1	300 m^2
2	Wind Turbines		Wind Energy Trees	10	Diameter 7.5 m; Height 10 m
3	Chemi-luminscence		Luminescent road	1	1500 m^2
4	Piezoelectrics		Piezoelectric Rain Farm	1	25 m^2

* Number of Elements in a farm = 7 Mushroom Tree

3.3 ENERGY CALCULATION RESULTS

The Energy calculations were made manually and using online software. An example manual calculation was done using Eq.3. The calculation was done for Photovoltaic floors.

The energy calculation for 1 m^2 PV Floor was calculated by using Eq.3:

$E = 365 * P_k * r_p * H_{h,i}$

P_k = 0.021 Wp, 0.0583 Wp for 1 m^2 {From Module 04TA_-16410989 Technical Datasheet (Onyxsolar, 2011)}

r_p = 0.75 {a typical value for polycrystalline silicon module (Šúri, Huld, Dunlop, Albuisson, & L., 2006)}

$H_{h,I}$ = 82.8 kWh/m^2 {Monthly Average calculated from PVGIS Results for horizontal surface}

365 is the number of days in a year but since monthly average was calculated, 12 is used in the calculation.

Energy, E	= 12 * 0.0583 * 0.75 * 82.8
	= 43.44 kWh * 0.36
	= 15.6 kWh
Solar Energy output of Single Module	= 15.6 kWh
Total number of modules	= 833
Total Energy output of PV Floor	= 15.6 * 833
	= 12994.8 kWh
	= 13 MWh

The PV Energy calculation was carried out using EU Commission's PVGIS web Tool (Photovoltaic Geographical Information System [PVGIS], 2017). The tool also calculates the PV modules' optimum inclination and orientation for harvesting maximum electricity over the whole year. The tool outputs a local horizon outline graph based on the 2-km digital elevation model (Šúri, Huld, Dunlop, Albuisson, & L., 2006) for the selected geographical location. The combined data of medium direct and disperse radiation onto the horizontal surface in Kaunas under medium cloudiness is shown in Fig. 37 (Photovoltaic Geographical Information System [PVGIS], 2017).

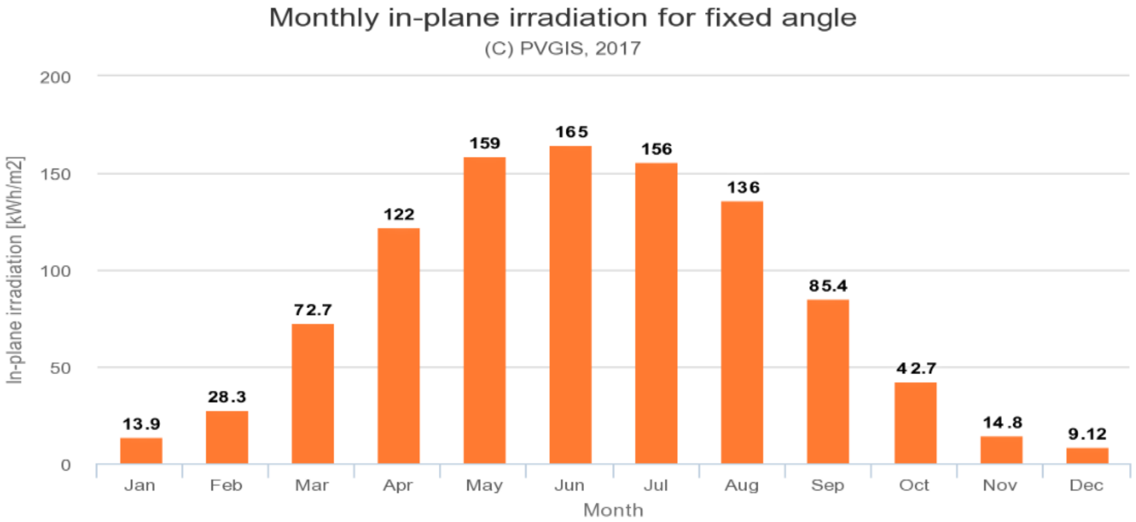


Fig. 37. Monthly Average Solar radiation data for a year in Kaunas for South Direction, Lithuania. [Source: Image retrieved using PVGIS-CMSAF Solar Radiation Database from PVGIS Tool, http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html]

Once the energy values are calculated for a module per annum, it is multiplied by the number of modules for the total energy output of the installed PV system.

The energy calculations of each of the different energy harvesting structures were calculated using PVGIS (Photovoltaic Geographical Information System [PVGIS], 2017). The generated calculations are presented in Annexure 1. The results were as follows:

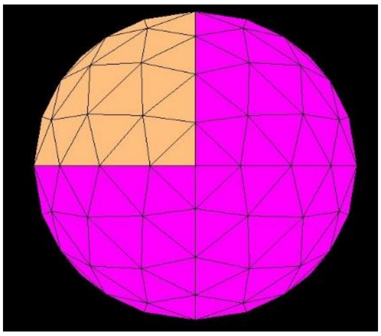
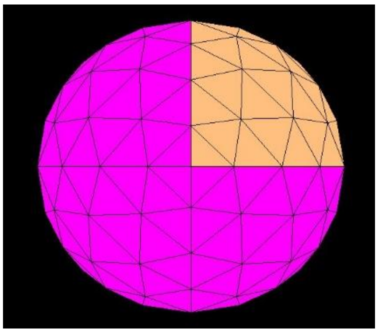
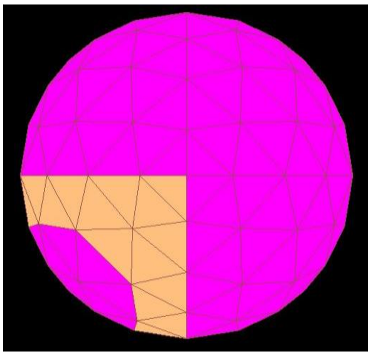
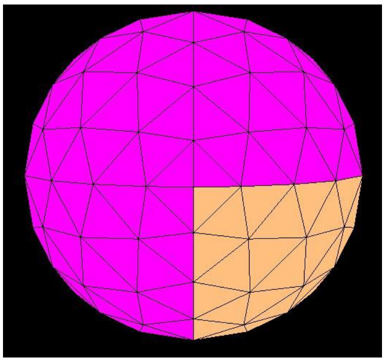
i. PV Geodesic Dome

The surface area of the 10 m diameter dome is 157.14 m^2 while PV panel covers only for 118 m^2. The angle of inclination could be anywhere from 35° – 45° around the curved slope and horizontal at the peak. Data assumed for the calculation are as follows:

- All panels are rectangular;
- The optimized mean Angle is 40°;
- PV Module: PV Crystalline Silica 04TA_-16410989 (Onyxsolar, 2011).

Energy production is provided in Table 2.

Table 2. Energy Production Calculation for PV Geodesic Dome

<table>
<tr><td colspan="2">Area = 29.5 m^2
No. of Panels = 24, Azimuth = -0° (North)
</td><td colspan="2">Area 29.5 m^2
No. of Panels = 24, Azimuth = 90°

(East)</td></tr>
<tr><td>Total Energy per year per panel = 253 kWh/an</td><td>Total Energy per year = 6.072 MWh/an</td><td>Total Energy per year per panel = 411 kWh/an</td><td>Total Energy per year = 9.864 MWh/an</td></tr>
<tr><td colspan="2">Area 19.71 m^2 (Entrance Side)
No. of Panels = 15, Azimuth = -90° (West)
</td><td colspan="2">Area 29.5 m^2
No. of Panels = 24, Azimuth = 0°

(South)</td></tr>
<tr><td>Total Energy per year per panel = 392 kWh/an</td><td>Total Energy per year = 5.88 MWh/an</td><td>Total Energy per year per panel = 505 kWh/an</td><td>Total Energy per year = 12.12 MWh/an</td></tr>
<tr><td colspan="4">Total Energy of the PV Geodesic Dome per year = 34 MWh/an</td></tr>
</table>

Note: Number of Panels is taken for Triangular panels and not rectangular, all figures were designed using CADRE Geo 7.

ii. Photovoltaic Floor

The PV floor is designed along the main path leading to the Science Island museum, proposed to be in the North Western end of the Island. Energy production is provided in Table 3.

Table 3. Energy Production Calculation for PV Floor and PV Geodesic Dome

Energy Harvesting Element	Area of Solar Panel (m^2)	Total Energy per year per panel (kWh/an)	Total covering Area (m^2)	No of Units	Total Energy per year (MWh/an)
PV Floor	0.36	13.5	300	833	11.2455

iii. Photovoltaic Trees

According to Sologic company, the total design capacity of a single unit of the suggested model is 800 Watts peak with 3.4 kW per day on average (Sologic, 2017). The electricity generated is in direct low voltage (DC).

The electricity produced from a single tree is 743 kWh per annum. The electricity produced from all trees is 74.30 kWh or 7.4 MWh per annum. The calculation was made using PVGIS.

iv. Wind Energy Trees

The wind data for Kaunas is shown in Fig. 38.

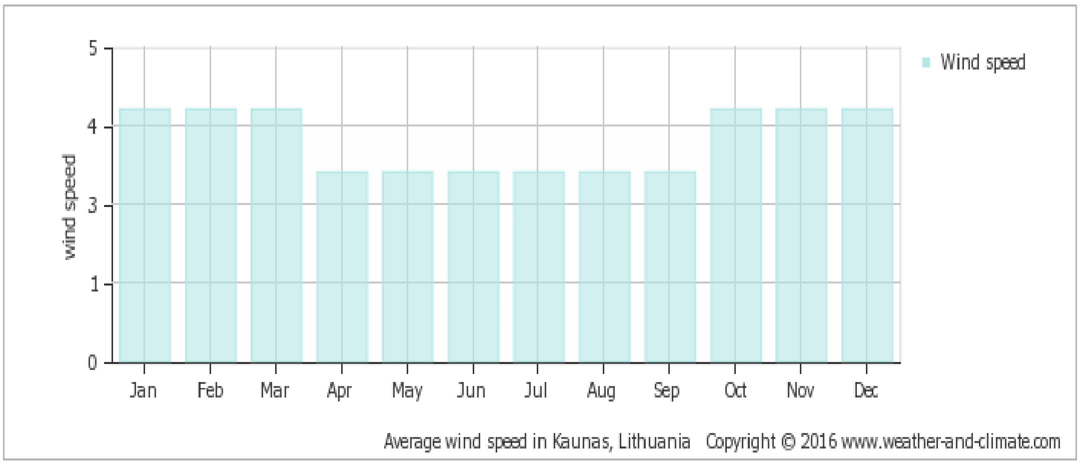


Fig. 38. Mean monthly wind speed at a standard height of 10 m above Ground level (meters per second) [Source: Image retrieved from https://weather-and-climate.com/average-monthly-Wind-speed,Kaunas,Lithuania]

The wind energy production is presented in Table 4.

Table 4. Energy Production Calculation for Wind Energy Trees

Installed capacity of a single tree	Total number of Trees	Total Capacity of installed trees	Estimated average production of a single tree in a year	Estimated average production of installed trees in a year
4.1 kW	10	41 kW	2400 kWh	24 MWh

It should be noted that the wind energy is calculated for a standard wind speed of 2 m/s and an activation threshold of 1.3 m/s.

v. Piezo Rain Farm

The energy produced from a Piezo rain farm in comparatively and considerably lower than that of the Solar Energy Harvesting and Wind Energy Harvesting. The sole purpose of the Piezo rain farm is for fun and play smaller led lights for children who visit the park. This proposed idea involves further research for energy calculations.

The energy calculations of all the Energy harvesting modules excluding the Piezo rain farm are summarised in Table 5:

Table 5. Comparison of Energy production by proposed Modules

Energy Harvesting Element	**No of Units**	**Total Energy per year in MWh/an**
PV Floor	833 PV floor tiles	11.245
PV Geodesic Dome	97 PV panels	34
PV Tree	10	7.4
Wind Energy Tree	10	24
Total		83.645

3.4 GRAPHIC DESIGNS OF THE PROPOSED ENERGY HARVESTING ELEMENTS

The proposed energy harvesting elements were designed using Sketchup Pro and were rendered using Lumion 4.2.5. Among the proposed elements, the piezoelectric rain farm has been re-designed in a newer concept. The idea of the re-design was to introduce concept of Bio-mimicry. In the proposed newer version, unlike the earlier idea, the farm elements are not smaller but larger structures incorporating solar panels on the surface. This was conceived under the idea that these piezoelectric rain farm will also act as a solar farm in the absence of rain. It should be noted that the earlier version will not produce electricity during sunny days of the year. This new design mimics the structure of a mushroom but on a larger scale (See Fig. 39, 40, 41). A part of the surface contains solar panels for the sunny days. The mushroom tree also incorporates led lights that glows during the night time with the electricity produced. The other benefits of this new piezoelectric rain farm is that it will also serve as a place where people could wait under during times of rain inside the park. The bio-mimic also makes aesthetically appealing on an architectural scale. However, the idea of which of the piezoelectric elements are to be used on the surface is for another research.

Fig. 39. A conceptual design of Piezo-electric rain farm Mushroom Trees (Night time view)

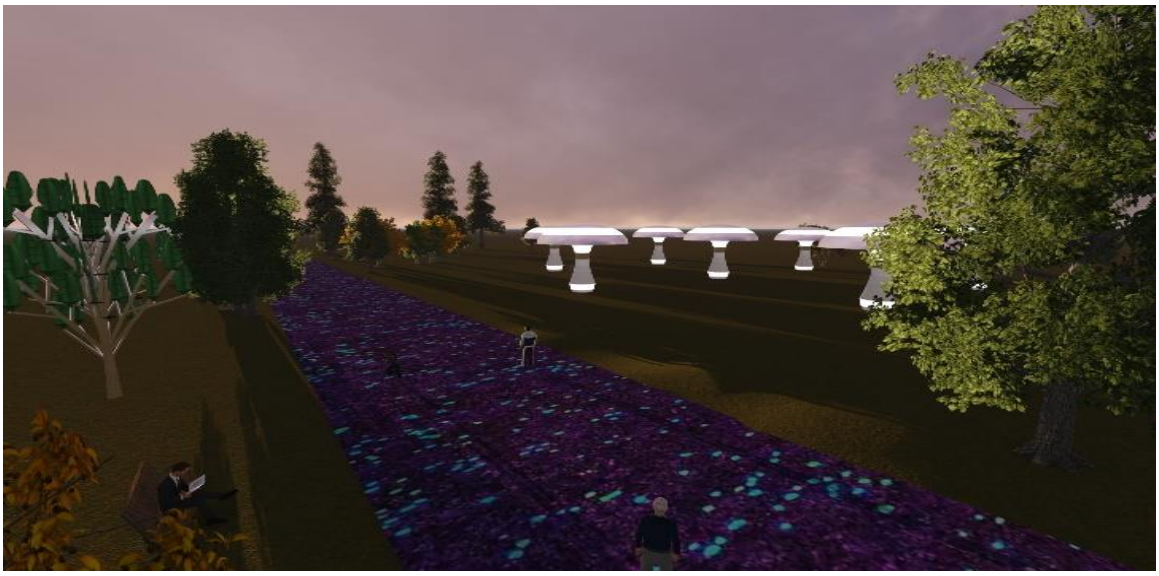


Fig. 40. A conceptual design of Piezo-electric rain farm, Wind Tree and Glow Aggregate Road (Evening time view)

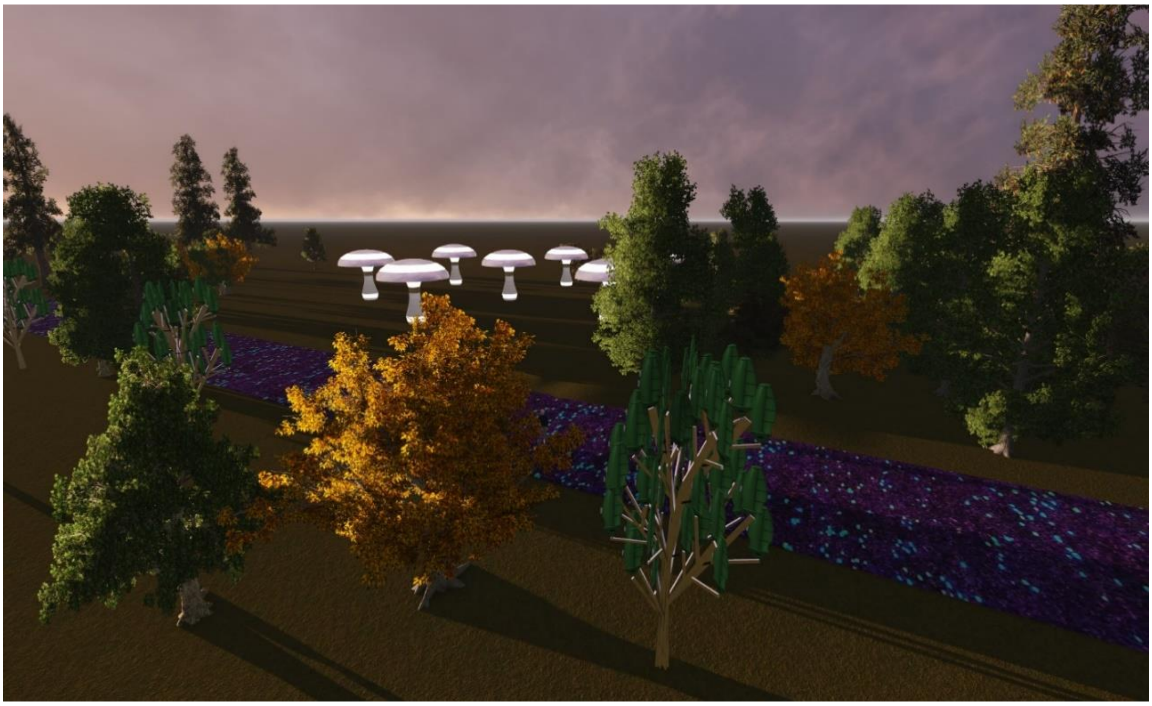


Fig. 41. – A conceptual design of Piezo-electric rain farm, Wind Tree and Glow Aggregate Road (Evening time view)

The PV Dome and PV Tree design is shown below in the Fig. 42.

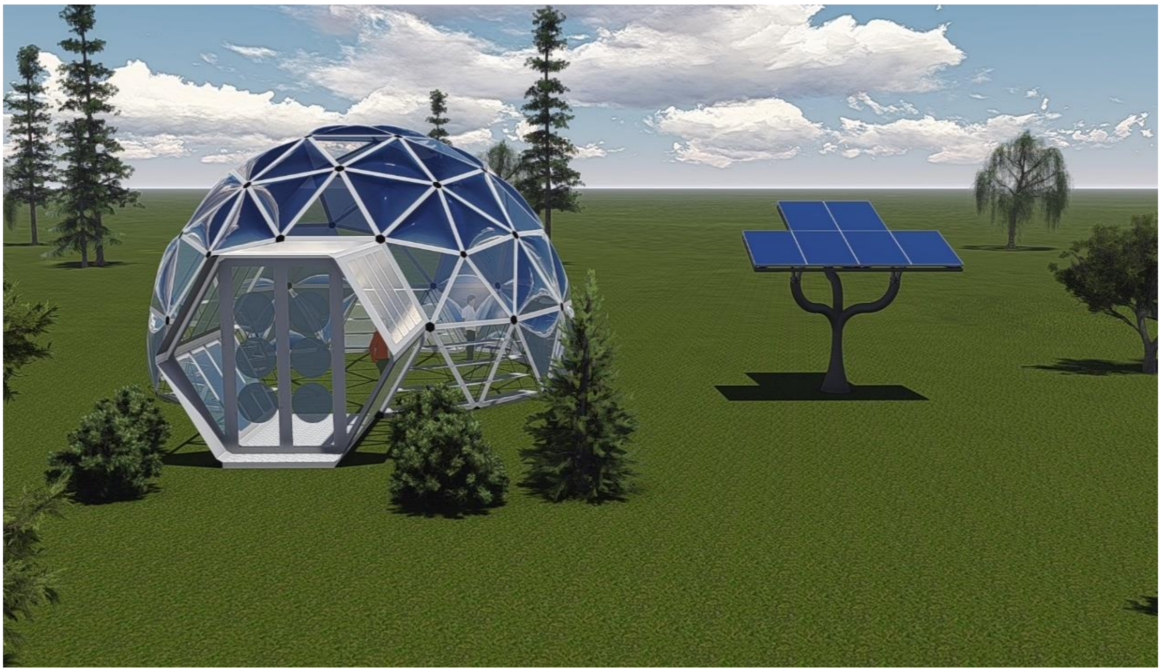


Fig. 42. A conceptual design of Solar Dome and Solar tree (Day time)

3.5 3D VIRTUAL REALITY MODELLING OF THE PROPOSED ENERGY HARVESTING ELEMENTS APPLIED IN VIRTUAL BUILT ENVIRONMENT

The sketchup Pro geolocation procedure for site modelling is shown in Fig. 43, 44.

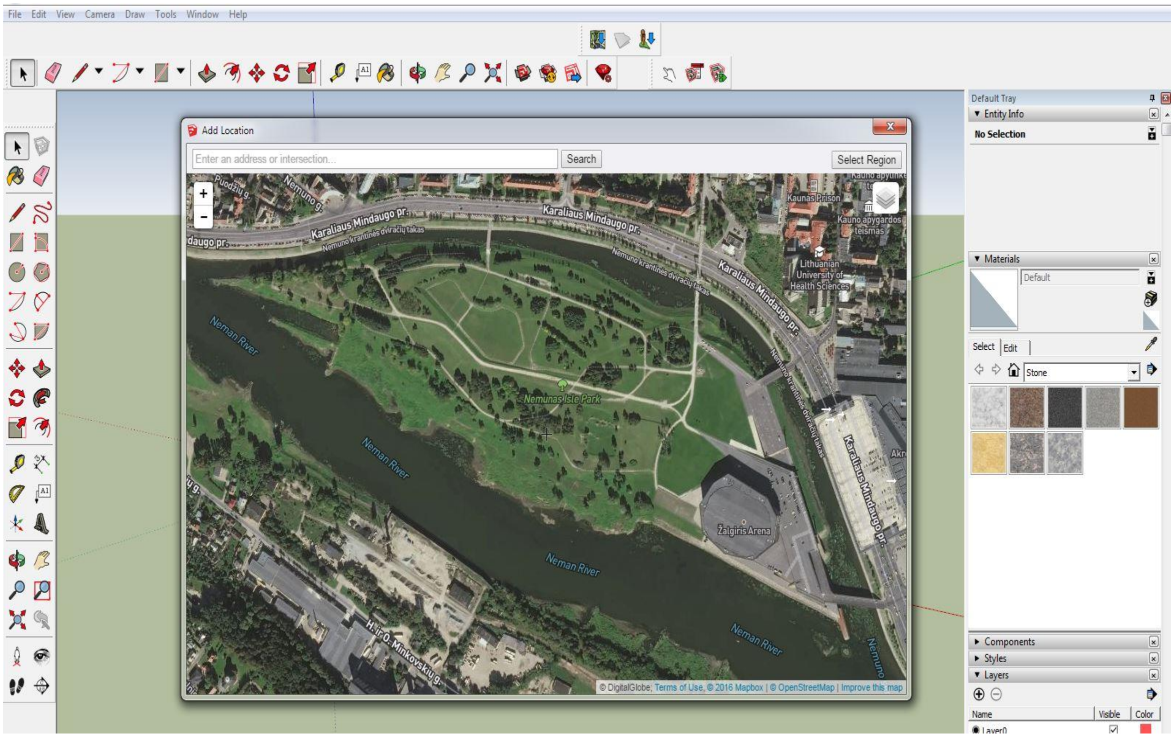


Fig. 43. A conceptual design of Solar Dome and Solar tree (Day time)

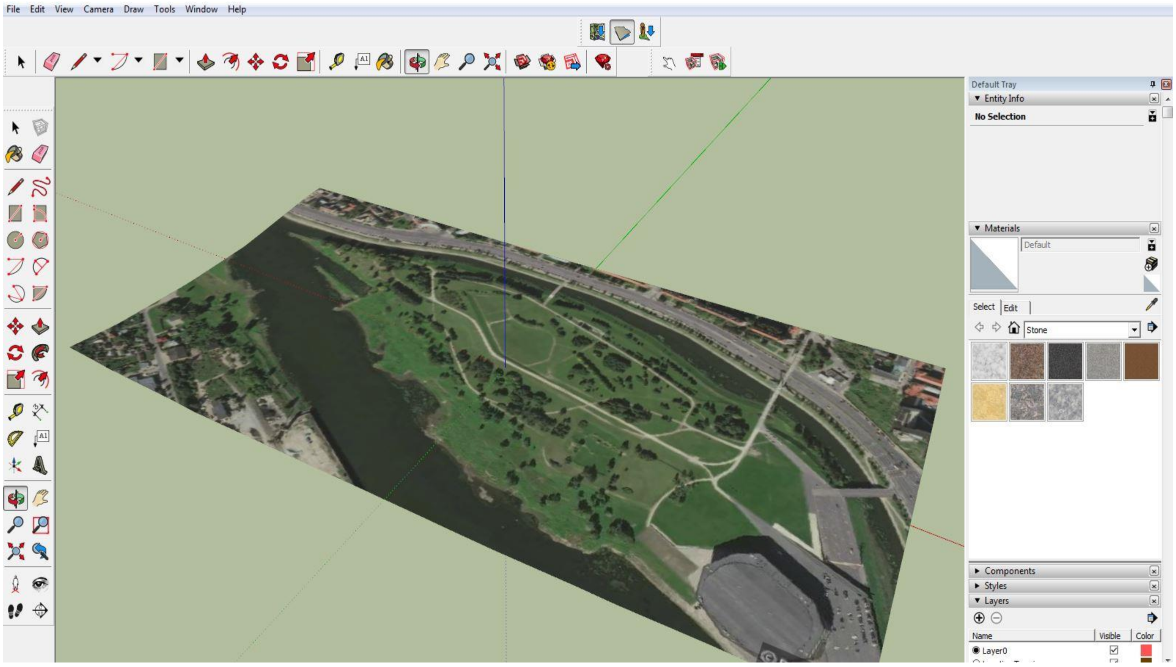


Fig. 44. A conceptual design of Solar Dome and Solar tree (Day time)

The Revit model is shown in Fig. 45 while the graphics rendered model is shown in Figures 46, 47, 48, 49, 50, 51 and 52.

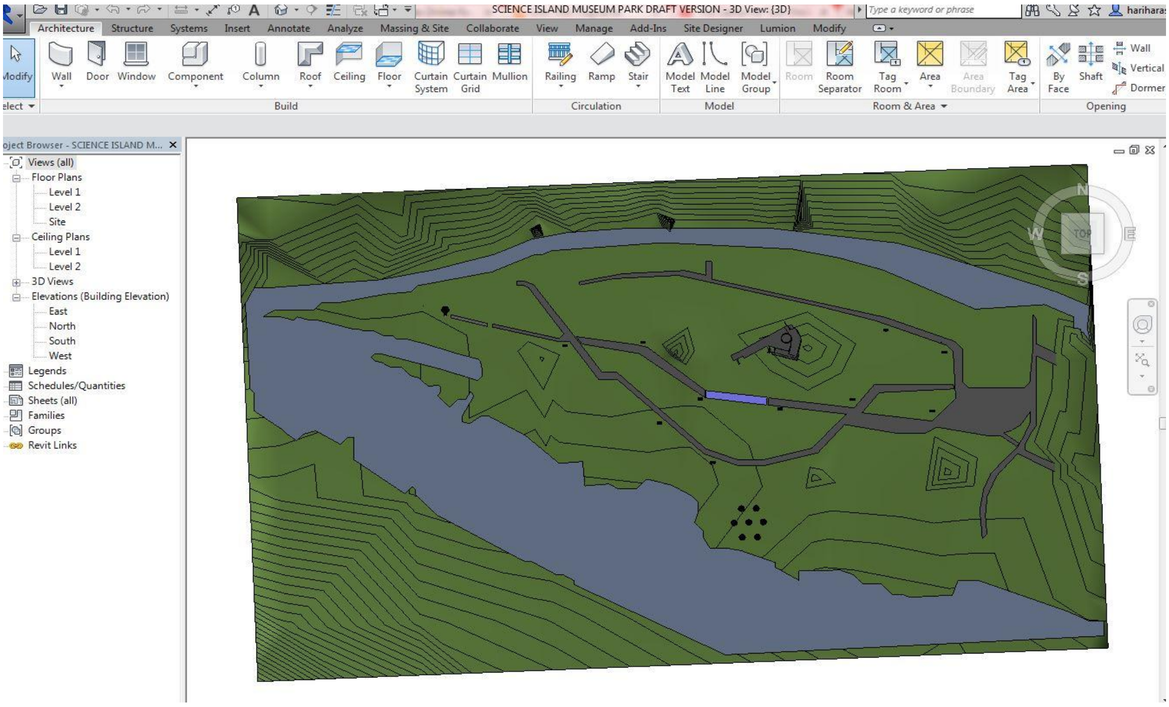


Fig. 45. Revit design of the Science Island Museum Park.

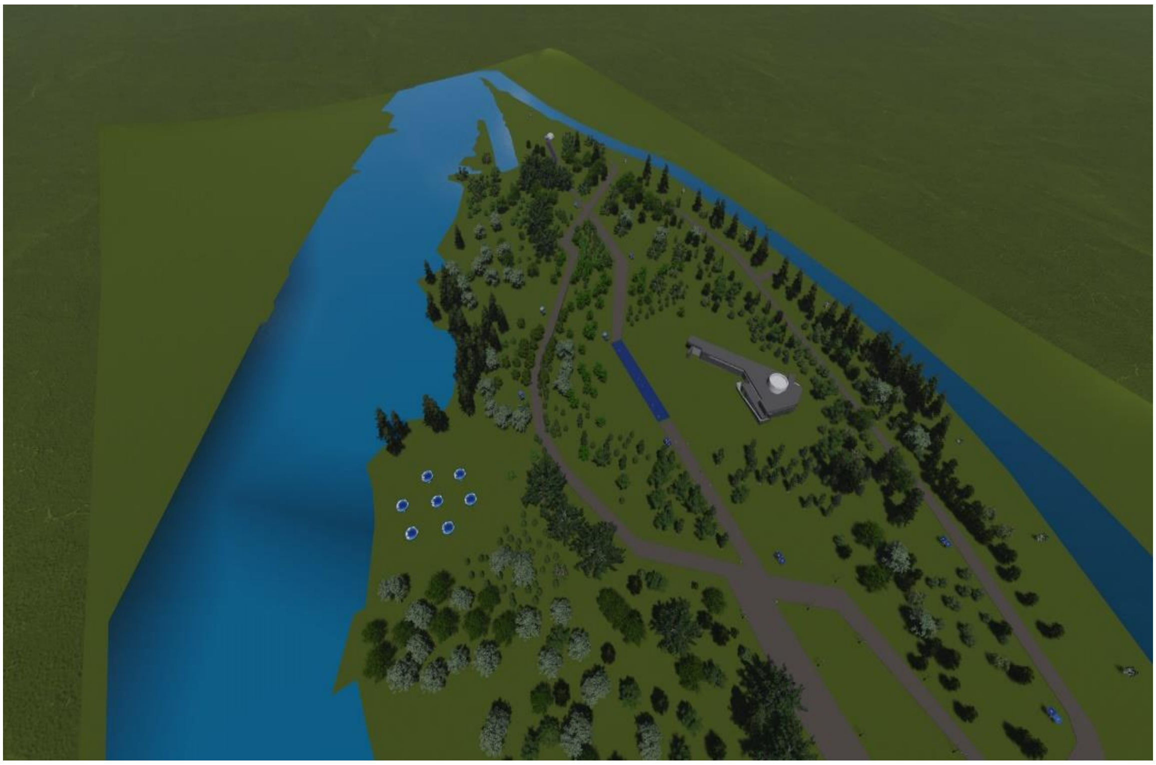


Fig. 46. Lumion rendered design of the Science Island Museum Park (Aerial view 1)

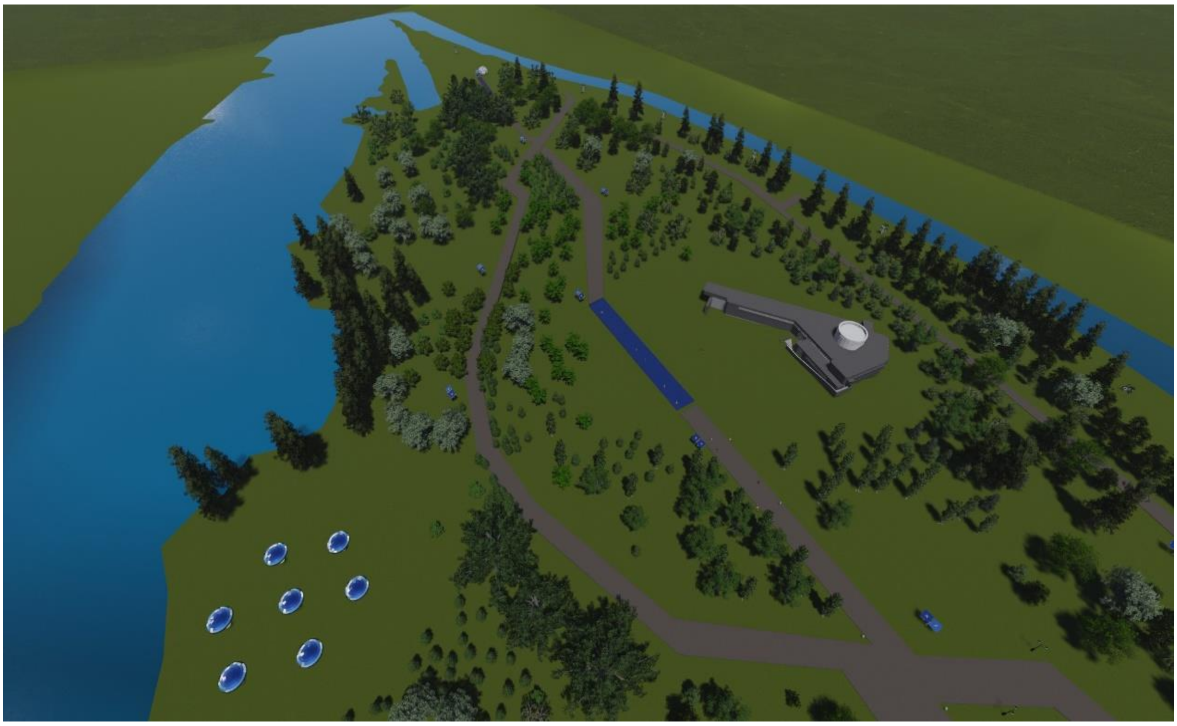


Fig. 47. Lumion rendered design of the Science Island Museum Park (Aerial view 2)

Fig. 48. Lumion rendered design of the Science Island Museum Park (Aerial view 3)

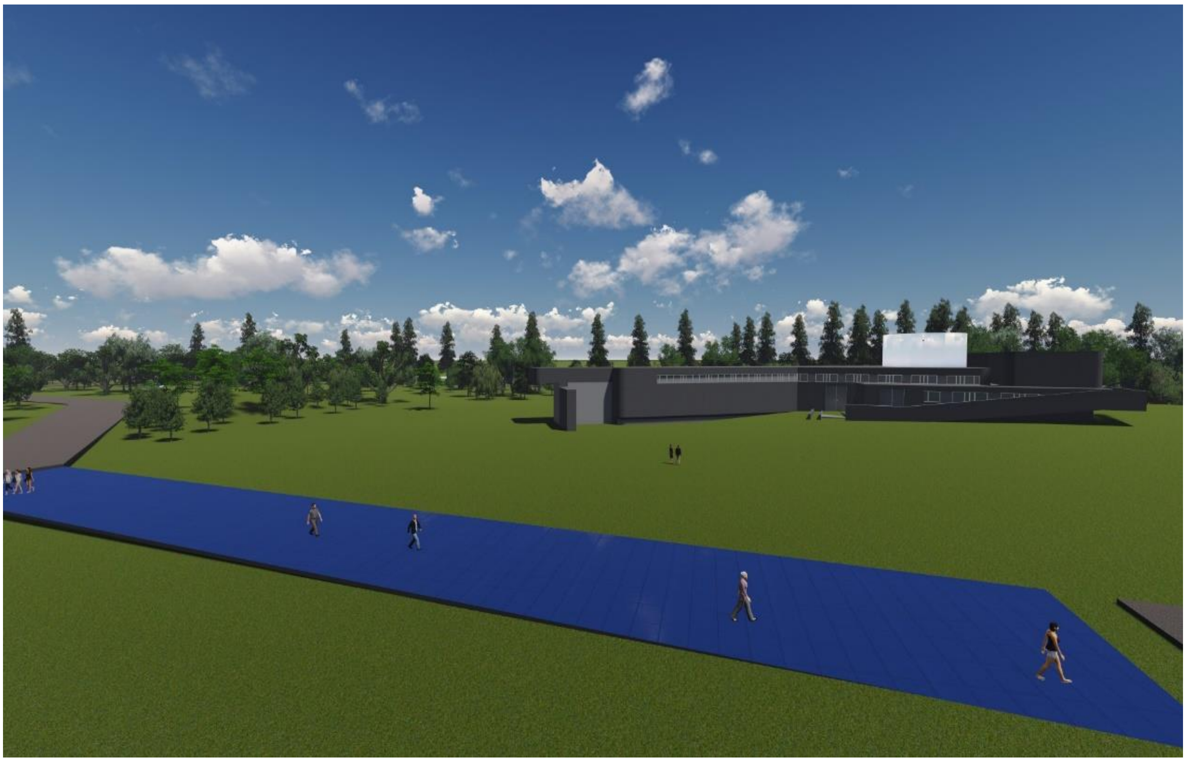


Fig. 49. Lumion rendered design of the PV Floor in Science Island Museum Park (Sub-Aerial Drone view)

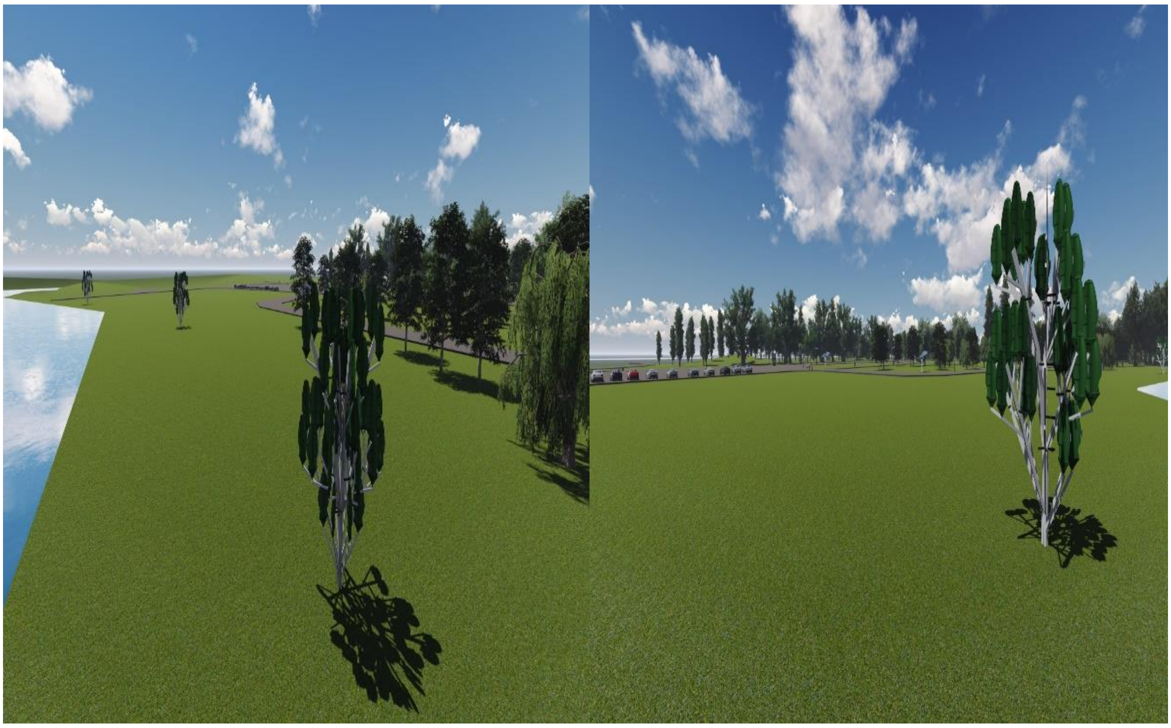


Fig. 50. Lumion rendered design of the Wind Tree in the Science Island Museum Park (Sub-Aerial Drone view)

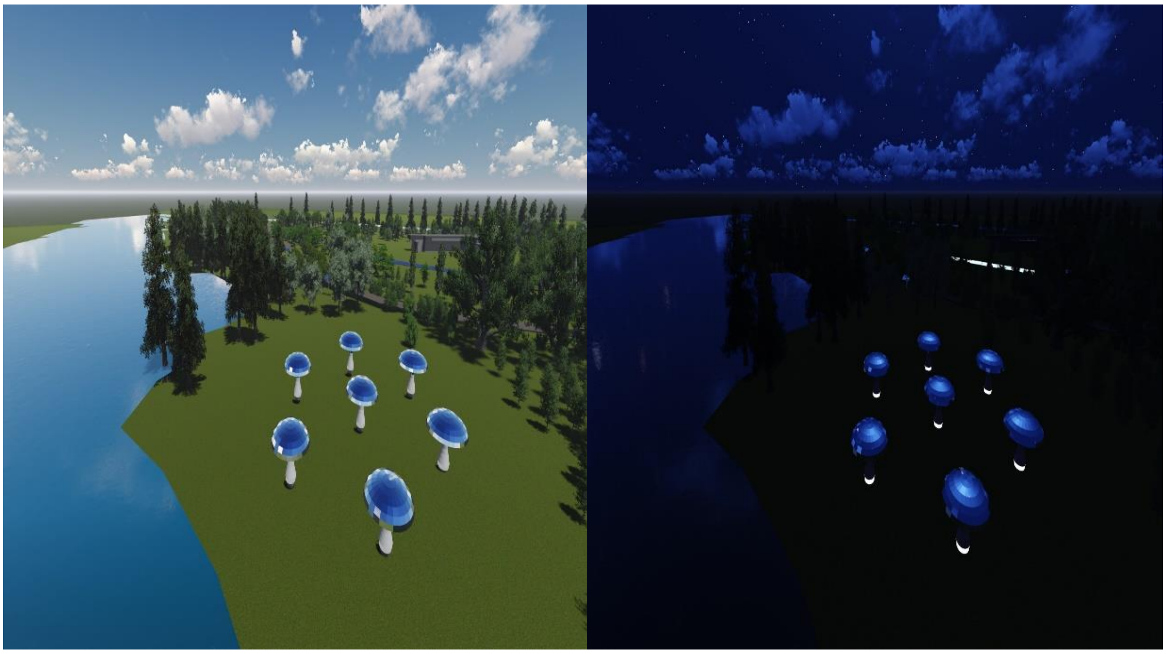


Fig. 51. Lumion rendered design of the Piezoelectric Rain farm in the Science Island Museum Park (Sub-Aerial Drone view at day and night time)

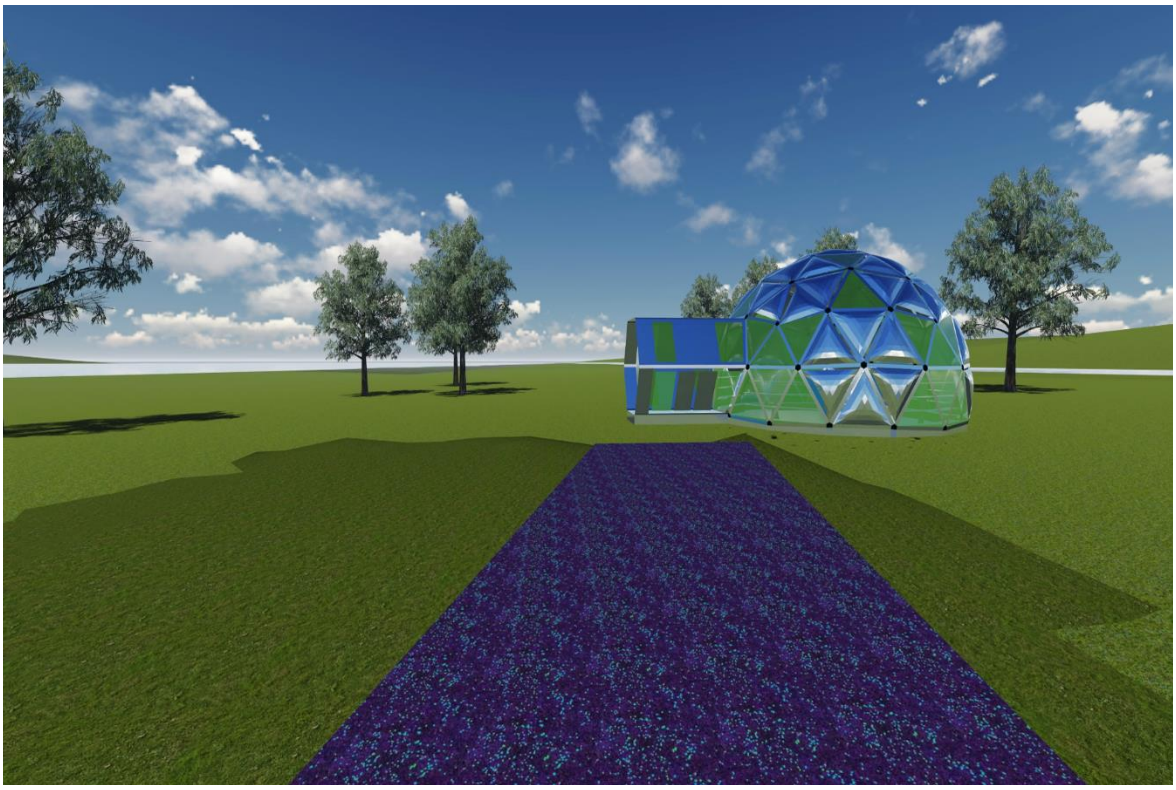


Fig. 52. Lumion rendered design of the Piezoelectric Geodesic Dome and Luminescent Road in the Science Island Museum Park (Ground view)

3.6 PROJECT SCHEDULING

The research application of the Innovative energy harvesting structures in the Built environment encourages using BIM.

Construction Project Management Report

The Construction Project Management Report, herein after referred to as the CPM Report used the *Critical Path Method* for scheduling the to be Project work. The methodology used here is to create a Work Breakdown Structure (WBS). A WBS was created which is shown in Table 6 for the construction of this project in the Science Island Park Area. Based on this WBS, the project scheduling and cost estimation is carried out. Refer to Annexure 2.

Table 6 Work Breakdown Structure of the proposed project.

WORK BREAKDOWN STRUCTURE (WBS)
Survey Park area site
Phase 1
Foundation Works for Solar Trees, Wind Trees and Solar Dome
Foundation works for Glow Pathway and PV Floor
Phase 2
Construction of Solar Dome
Installation of Solar Trees
Installation of Wind Trees
Layout of PV Floors
Layout of Glow Pathway
Phase 3
Layout of Piezo-Rain farm
Final Landscaping Architecture and Electrical Lamping Works

3.7 COST ESTIMATION RESULTS

The Science Island Museum's building cost is estimated at 25 million Euros (Malcolm Reading Consultants, 2017). The total cost of the Science Island Park project is 1.2 Million Euros. The total cost of the project incorporating Innovative Energy Harvesting Exposition Park would be 26.2 million Euros. The estimated budget presented in this book covers all the cost including the transports, Risk assessment and meet out cost, etc. Refer to Annexure 3.

The Construction cost is estimated based on the work schedule. This includes the cost of each Energy harvesting element, labour cost, construction materials cost. The details of the cost of each of the energy harvesting element is presented in Table 7.

Table 7. Cost Overview of Energy Harvesting Elements

Description	Quantity	Cost/ Item	Total Cost
Photovoltaic Geodesic Dome	1	€200 x 97 pieces + € 54000*	€73400
Photovoltaic Trees	10	€30,000	€300,000
Photovoltaic Floor	1	€150	€125,000
Wind Energy Trees	10	€49,500	€495,000
Piezo Rain Farm	1	-	-

* PV Geodesic Dome cost = Cost of PV Tile + Cost of Dome Structure

3.8 DISCUSSION

Manual calculation result was higher than the PVGIS tool estimated value. However, there are few things that are to be accounted for the difference of values. They are,

- While the manual calculation uses the values without considering the energy storage, i.e. if it is battery stored or Grid connected, the PVGIS tool estimates the value for Grid connected,
- The PVGIS tool uses real time Geographical Information System while manual calculation does not. The real time GIS uses the latitude and longitude reference of the site location and uses statistical meteorological data of previous years for that location. This gives an edge over the manual calculation values.
- One of the other significant part of the PVGIS tool that has an advantage over the manual calculation is that it provides Optimized tilt angle. An optimal tilt angle calculation is possible manually but is a tedious process.

Based on the results, it could be observed that by utilizing the different proposed energy harvesting elements, approximately 84 MWh of energy can be produced in the Science Island museum park per year. The calculated figures may vary depending on the final technology selection and site design. If the number of solar trees and wind trees are reduced, the total cost of the project will be reduced significantly. This project proposal is made as an idea that might be presented to the City council of Kaunas Municipality**.**

For the Fiscal Year 2015, the Lithuanian Department of Statistics observed that the share of Renewable Energy Sources in the electricity sector was 1.740 GWh in which wind plants accounted for 48 % of the energy generated; while Solar power plants accounted only for 4.2 % (Ministry of Energy of the Republic of Lithuania, 2017). Based on that fact, it is evident that Wind Energy production is more than Solar Energy production. The number of Wind Energy structures could be increased for more energy production.

The advantages of using VR construction technology modelling are:

a. Individual Experience Customizations,
b. Real – World Scenario Simulations,
c. Coordinated BIM Implementation,
d. Client Satisfactory Design Implementation,

With the Project designed in Virtual reality, the application in Built Environment was observed in real time, before the constructions. Although Computer based VR tools like Oculus Rift or HTC Vice were not used in the VR experience, the immersive experience was very much overwhelming with just Lenovo VR Headset.

The different forms of energy harvesting methods are aimed to promote the values of Science and technology among the people visiting the Museum and the Island. The entirety of the proposed Science Island, at the time of writing this thesis is still only in the proposed stage and constructions haven't begun yet. The Kaunas City council intends the project to be International.

4. CONCLUSIONS

1) Upon reviewing various Scientific and General Literature, it was found that Germany leads the World in Renewable Energy Production. It was also observed that in Lithuania, the trend for constructing Renewable energy harvesting structures is on the rise in recent years.

2) The energy calculation methodology was discussed using Formulae based on the scientific principles of Solar Radiation and Wind Power. It was found that the amount of Photovoltaic energy directly depends upon the duration, amount and angle of the solar radiation. In case of wind power, it was observed that factors like wind speed, wind direction play significant role in the production of wind energy. The different innovative energy harvesting elements proposed were PV Geodesic Dome, PV Floor, PV trees, Wind Energy harvesting Trees and Piezoelectric rain farm. Besides these elements, an electricity free luminescent pavement with glow aggregates was also presented. The construction and installation practices for each of the proposed energy harvesting structures were outlined as well. In addition to that, for demonstration purpose, a simple concrete paver block embedded with synthetic glow stones was made.

3) The Virtual Reality Design methodology was applied to create a virtual built environment using software: Sketchup Pro, Revit, Lumion; hardware: ANT VR headset, Lenovo K4 Note, Laptop and design procedures. The virtual built environment was converted to VR video format for viewing through the VR glass.

4) The thesis applied the research work by utilizing the park area around the Science Island museum in the Nemunas River Island in Kaunas by installing innovative energy harvesting structures incorporated into Landscape Architecture. Three different layouts of the installations around the park area were suggested and the third layout was selected to be the most functionally appealing. From the calculations, the energy production values of each energy harvesting elements were calculated as,
   a. Energy of PV Dome = 34 MWh/an
   b. Energy of PV Floor = 11.245 MWh/an
   c. Energy of PV Trees = 7.4 MWh/an
   d. Energy of Wind Trees = 24 MWh/an

   The total energy production from the proposed Energy harvesting structures was estimated to be around 84 MWh. The total cost of the Project was estimated about 1.2 million Euros.

DISSEMINATION OF THE RESULTS

The results of this Master's Degree Final Project were presented:

1. As Poster Presentation titled "Innovative Energy Harvesting Exposition Park of Kaunas Science Island Museum" authored by Hariharasubbu Balamoorthy and co-authored by Assoc Prof. Dr. Rasa Apanaviciene in the International scientific conference "Ecological Architecture 2017" held at Faculty of Civil Engineering and the Architecture at Kaunas University of Technology (See Appendix),

2. As Conference Proceedings Publication under the title "Construction of Innovative Energy Harvesting Exposition Park in Kaunas Science Island" authored by Hariharasubbu Balamoorthy and co-authored by Assoc Prof. Dr. Rasa Apanaviciene in the International scientific conference "Ecological Architecture 2017" held at Faculty of Civil Engineering and the Architecture at Kaunas University of Technology (See Appendix),

3. As Scientific paper titled "Innovative Energy Harvesting Exposition Park of Kaunas Science Island Museum" authored by Hariharasubbu Balamoorthy and co-authored by Assoc Prof. Dr. Rasa Apanaviciene in Journal of Sustainable Architecture and Civil Engineering. The paper was accepted for publication on 22 December 2017 and is in the process of publication at the time of the submission of this thesis work (See Appendix).

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All Photovoltaic Calculations were made using PVGIS5, PVGIS © European Communities, 2001-2012.

PV Geodesic Domes were designed using CADRE Geo 7 (Evaluation version), AutoCAD 2018.

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ANNEXURES

ANNEXURE 1

PVGIS CALCULATIONS

Calculations for PV Geodesic Dome

Calculations for PV Floor

Calculations for PV Trees

ANNEXURE 2

DETAILED PROJECT SCHEDULING (MODEL ONLY)

Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
Auto Scheduled	**Project1**	**4.2 wks**	**Mon 24-10-16**	**Mon 21-11-16**		**B-Work,B-Cost**
Manually Scheduled	**Construction Activity of Science Island Park with Energy Harvesting Structures incorporating Landscape Architecture**	**0 wks**	**Mon 24-10-16**	**Mon 24-10-16**		
Auto Scheduled	START	0 wks	Mon 24-10-16	Mon 24-10-16		
Auto Scheduled	Survey Park area site	3 days	Mon 24-10-16	Wed 26-10-16	2	Surveyor 1,Surveyor 2,Theodolite,Total Station,Project Director,Technical Labour 1,Technical Labour 2
Manually Scheduled	Phase 1	0 days	Thu 27-10-16	Thu 27-10-16	3	
Auto Scheduled	Foundation Works for Solar Trees, Wind Trees and Solar Dome	2.8 days	Thu 27-10-16	Mon 31-10-16	4	Engineer 1,Project Director,Technical Labour 1,Technical Labour 2,Trencher
Auto Scheduled	Foundation works for Glow Pathway and PV Floor	2 days	Thu 27-10-16	Fri 28-10-16	4	Project Director,Engineer 2,Technical Labour 3,Technical Labour 4,Trencher
Auto Scheduled	Phase 2	0 days	Mon 31-10-16	Mon 31-10-16	6,5	
Auto Scheduled	Construction of Solar Dome	4.2 days	Mon 31-10-16	Fri 04-11-16	7	Engineer 1,Engineer 2,Electrician 1,Electrician 2,Project Director,Mini Crane,Technical Labour 1,Technical Labour 2,Technical Labour 3,Technical Labour 4
Auto Scheduled	Installation of Solar Trees	6 days	Mon 07-11-16	Mon 14-11-16	8	Electrician 1,Electrician 2,Project Director,Engineer 1,Mini Crane,Technical Labour 1,Technical Labour 2
Auto Scheduled	Installation of Wind Trees	4 days	Mon 07-11-16	Thu 10-11-16	8	Mini Crane,Engineer 2,Project Director,Electrician 3,Electrician 4,Technical Labour 3,Technical Labour 4
Auto Scheduled	Layout of PV Floors	2 days	Tue 15-11-16	Wed 16-11-16	9	Electrician 1,Electrician 2,Electrician 3,Electrician 4,Engineer 1,Project Director
Auto Scheduled	Layout of Glow Pathway	2 days	Fri 11-11-16	Mon 14-11-16	10	Engineer 2,Project Director,Road Roller,Technical Labour 3,Technical Labour 4,Mason 1,Mason 2
Auto Scheduled	Phase 3	0 days	Wed 16-11-16	Wed 16-11-16	11,12	
Auto Scheduled	Layout of Piezo-Rain farm	2 days	Thu 17-11-16	Fri 18-11-16	13	Electrician 1,Electrician 2,Engineer 1,Technical Labour 1,Technical Labour 2
Auto Scheduled	Final Landscaping Architecture and Electrical Lamping Works	3 days	Thu 17-11-16	Mon 21-11-16	13	Engineer 2,Project Director,Technical Labour 1,Technical Labour 2,Technical Labour 3,Technical Labour 4
Auto Scheduled	END	0 wks	Mon 21-11-16	Mon 21-11-16	15,14	

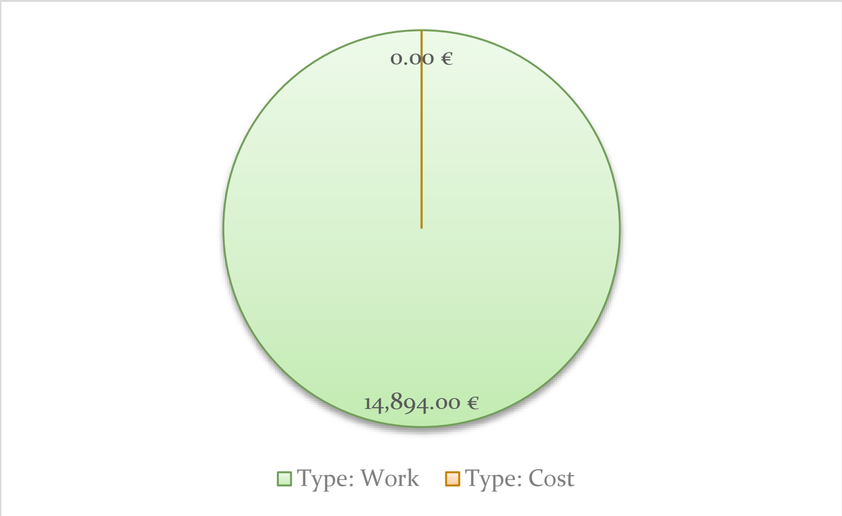
Note: The Start Date is only for model purpose and the real start date of the Project if implemented is subject to change.

ANNEXURE 3

COST DISTRIBUTION ANALYSIS (MODEL ONLY)

COST DISTRIBUTION

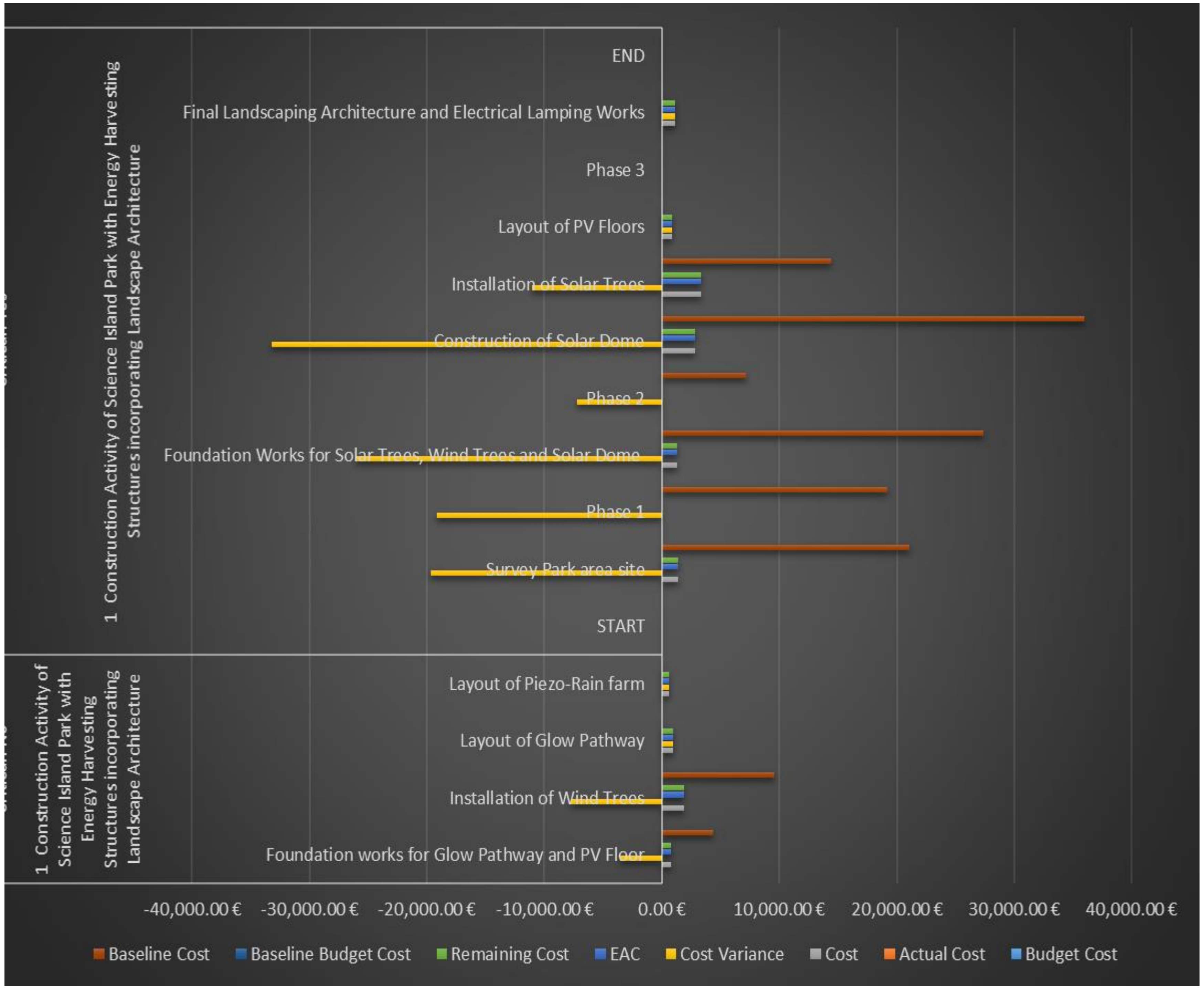
How costs are spread out amongst different resource types.



Cost details for all work resources.

Name	Actual Work	Actual Cost	Standard Rate
Surveyor 1	0 hrs	0.00 €	50.00 €/day
Surveyor 2	0 hrs	0.00 €	50.00 €/day
Technical Labour 1	0 hrs	0.00 €	50.00 €/day
Technical Labour 2	0 hrs	0.00 €	50.00 €/day
Technical Labour 3	0 hrs	0.00 €	50.00 €/day
Technical Labour 4	0 hrs	0.00 €	50.00 €/day
Engineer 1	0 hrs	0.00 €	100.00 €/day
Engineer 2	0 hrs	0.00 €	100.00 €/wk
Mason 1	0 hrs	0.00 €	50.00 €/day
Mason 2	0 hrs	0.00 €	50.00 €/day
Electrician 1	0 hrs	0.00 €	50.00 €/day
Electrician 2	0 hrs	0.00 €	50.00 €/day
Electrician 3	0 hrs	0.00 €	50.00 €/day
Electrician 4	0 hrs	0.00 €	50.00 €/day
Project Director	0 hrs	0.00 €	150.00 €/day
Mini Crane	0 hrs	0.00 €	100.00 €/day
Theodolite	0 hrs	0.00 €	50.00 €/day
Total Station	0 hrs	0.00 €	50.00 €/day
Trencher	0 hrs	0.00 €	100.00 €/day
Road Roller	0 hrs	0.00 €	100.00 €/day
B-Work			

Note: The cost estimation may differ



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APPENDIX

International scientific conference "Ecological Architecture 2017"