DESIGN FOR PV-INTEGRATED SMART URBAN FURNITURE

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ABSTRACT

DESIGN FOR PV-INTEGRATED SMART URBAN FURNITURES

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Urban furniture has always been integrational part of cities. They have the potential as social spaces as well as acting as a resting space in the urban context. In recent years the new term Smart Urban Furniture brought about new services and uses for urban furniture rather than serving as public meeting space. Smart urban furniture is equipped with chargers and other energy demanding services. It also contributes to the development of environment respected implementations. Recent concerns of climate change have forced urban living in many ways. The design and working principle of urban furniture has also been an essential part of this concern. While providing people services and a comfortable space for various activities, to reach this goal with clean energy is the main focus. In order to supply energy to the Urban furniture, PV panels are the main tools. PV energy generation also has the potential to power e-mobility in cities, furthering efforts in the de-carbonization of transport systems. However, while taking into consideration the energy needs, urban furniture design lacks two main essential elements in practice: The architectural concern of design, and analysis based design methodology. The method is based on the analysis of the climate, physical environment, various formal characteristics, materials as well as the materials of construction. Modularity is another design criterion, which allows the flexibility, adaptability and scalability of the proposed designs. As a result, future potentials to use the method for different contexts is also discussed in this thesis study.

Keywords: Smart Urban Furniture, Urban Photovoltaics, E-Mobility, Thermal Comfort, Architectural Integrity

ÖZ

PV BÜTÜNLEŞİK AKILLI KENT MOBİLYALARI İÇİN TASARIM

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Kent mobilyaları her zaman kentlerin tamamlayıcı parçaları olmuştur. Kentsel bağlamda dinlenme alanı olmalarının yanı sıra sosyal mekân potansiyeline de sahiptirler. Son yıllarda yeni dönem Akıllı Kent Mobilyaları, kamusal bir toplanma alanı olmaktan ziyade kent mobilyalarına yeni hizmetler ve kullanımlar kazandırdı. Akıllı kent mobilyaları, şarj cihazları ve diğer enerji gerektiren hizmetlerle donatılmıştır. Ayrıca bu mobilyalar çevreye saygılı uygulamaların geliştirilmesine de katkı sağlamayı amaçlarlar. Ancak son dönemde iklim değişikliğine ilişkin endişeler kent yaşamını birçok açıdan zorladı. Kent mobilyalarının tasarımı ve işleyişi de bu endişenin önemli bir parçası olmuştur. İnsanlara hizmet ve çeşitli aktiviteler için konforlu bir alan sağlarken, bu hedefe temiz enerjiyle ulaşmak ana odak noktası haline geldi. Bu bağlamda kent mobilyalarına enerji sağlamak için PV paneller ana araçlar haline geldi. PV enerji üretimi aynı zamanda şehirlerdeki elektrikli ulaşıma güç sağlama potansiyeline sahip olup, ulaşım sistemlerinin karbonsuzlaştırılmasına yönelik çabaları daha da ilerletmektedir. Ancak enerji ihtiyaçlarını göz önünde bulundururken, kentsel mobilya tasarımı pratikte iki temel unsurdan yoksun hale gelmiştir: Tasarımın mimari kaygısı ve analize dayalı tasarım yöntemi. Sürdürülebilir bir kent mobilyası tasarımı için bu iki faktör çok önemlidir. Yöntem iklimin, fiziksel çevrenin, çeşitli biçimsel özelliklerin, malzemelerin yanı sıra inşaat malzemelerinin analizine dayanmaktadır. Modülerlik, önerilen tasarımların esnekliğine, uyarlanabilirliğine ve ölçeklenebilirliğine olanak tanıyan bir diğer tasarım ölçütüdür. Yöntemin farklı bağlamlarda kullanılmasına yönelik gelecekteki potansiyeller de bu tez araştırmasında tartışılmaktadır.

Anahtar Kelimeler: Akıllı Kent Mobilyaları, Enerji Simülasyonu, Radyasyon Analizi, Isıl Konfor, Mimari Bütünlük

To my Mother…

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ABBREVIATIONS	
SART	Solar Adjusted Radiant Temperature
VIPV	Vehicle Integrated Photovoltaics
IT	Information Technology
GHG	Green House Gas
SUF	Smart Urban Furniture

CHAPTER 1

INTRODUCTION

Cities are environments where people have the opportunity to respond their social needs. While hosting as a meeting space for people, cities continuously change their appearance, which inevitably reshapes the interaction among people. Especially city squares are playgrounds for people from various backgrounds. The changing conditions in cities have urged the spaces to become more efficient in many ways. This introduced the term “Smart Cities” to the literature and market. “Smart cities represent a conceptual urban development model on the basis of the utilization of human, collective, and technological capital for the development of urban agglomerations (Angelidou, 2014). The term could easily be associated with sustainable cities and climate change. Ahvenniemi (2017) states “Terms used for smart cities in different studies are largely used interchangeably, and include references to sustainable cities, green cities, low-carbon cities, eco-cities, intelligent cities, resilient cities, knowledge cities, and digital cities”. Chesear et al. (2023) states, “The introduction of these smart street furniture devices was inextricably associated with aspirations in the technology sector and local governments to transform urban spaces into ‘smart cities’”. Angelidou (2015) indicates that, “What is certain, though, is that smart cities represent a multidisciplinary field, constantly shaped by advancements in technology and urban development”. The term smart indicates as mentioned in Grossi and Pianezzi (2017), “Smartness is identified with a general concept of innovation and with a substantial use of technologies –precisely those technologies that the economic actors involved in this process of enhancing the public good are able to provide”.

Urban equipment became tools to respond the needs. They evolved as chairs, tables, resting spaces and other elements that serve to the changing conditions. Ertürk and Uslu (2019), state "Urban furniture is the equipment that have been built in different cultures throughout the history in order to maintain the order of society in urban life." Especially the subject field for urban furniture is city squares and neighborhoods. Prvanov (2019) states, "Besides providing various uses to satisfy the different needs of users, street furniture design includes the consideration of the total urban landscape in creating a comfortable and convenient urban environment."

Recent years has opened up a new stage for the urban furniture. The term "Smartness" has infused to the very core of the city life. The large investments in renewable energy put human comfort and environmental concerns into the fore. Cities are planning to become more energy efficient in order to establish a low carbon economy. "To shift urban management toward a citizen orientation, cities personalize and improve the efficiency of their local services, provide citizens with choice and detailed urban information, and facilitate citizen–infrastructure interactions, among other strategies" (Belanche et al., 2015, as cited in. King & Coterill, 2007). The increasing energy needs for vehicles, communication tools and other electric powered systems, has urged the change of urban furniture. In 2003, Ito et al. stated, ''Smart Furniture is a platform for systems to realize Smart Hot-spots. By simply placing the Smart Furniture, we can turn legacy spaces into Smart Hotspots. Therefore, this thesis research focuses on the smart solar urban furniture. In this sense, smart urban furniture belongs under the umbrella of Smart Cities. Technavio (2018) states, "Smart furniture is powered by technological advances such as network connectivity via Bluetooth or Wi-Fi and others, which helps users enhance their furniture beyond its basic analogue functions". Smart Urban Furniture are also equipped with electric chargers that respond to the needs of smart phones and laptops. Not only this, but also the rising numbers of electric bicycles and scooters have opened a new demand for electric chargers in cities. Given the energy responding services of Smart Urban Furniture, the material of these structures state also an important role. Providing zero carbon emission services with sustainable and zero carbon emitting materials is also the aim of solar smart urban furniture. Under these conditions, implementing solar panels to urban furniture is one of the most common solution for providing electricity for demanded services.

The need for smart urban furniture is certain. The rising technological developments has carried the smart services from our offices, and homes to outside. People gather around and arrange meetings in open public points. Not only meetings, but also individuals use their laptops, phones and other technological devices in open public spaces. Inevitably, the need for places that would respond to the needs mentioned above becomes certain. Charging units, and other usb apparatuses are imperative, since they revive the urban furniture spots, and entitle new services to these structures.

In contrast to the increasing needs of smart urban furniture system in cities, one of the problem is the visual impact of solar panels in urban context. Despite of the increase of smart urban furniture, the design and implementation of these structures lack architectural quality. In this sense it can be considered as a deficiency for urban furniture. In that manner, Munari Probst & Roecker (2012) states, “It is always important to stress out the strategic role of architectural design for visual integration of photovoltaics and this can be achieved only with customized design and following guidelines developed by the councils”. Various products in the market lacks architectural design such as, street lights, solar benches ext. In this sense the thesis indicates the need for architectural design in smart urban furniture design and the ongoing room for this. In fact, the architectural visibility, sensitivity and quality of solar technology defines architectural quality in smart urban furniture. Therefore, **modularity**, **geometry** and **material** of design state a critical role. In order to provide various combinations for distinct uses modularity is the key stone. Not only, architectural quality, but also the urban context is imperative in the making of smart urban furniture process. It evaluates the design’s adaptability to the local area. The climatic situation and socio cultural value is the role maker for the urban context.

The assessment and evaluation of the context in terms of socio cultural manner is called **Urban Sensitivity**.

Within the climatic conditions of an urban area, the structures positioning and form is important for the compatibility to the context. Simulations and 3D models are useful, in order to assess the climatic impact of the context to the structure. Simulating the solar irradiance on surfaces has a direct impact on the generation of solar energy. Given the solar analysis, the 3D models also imitate the surrounding environment and simulates the shadow ration on certain surfaces. “Based on the 3D city model of new urban developments and existing environments, solar simulation tools for 3D modelling can help in the design of the furniture form optimizing the solar utilization” (Lundgren et al., 2018). For this reason, in the making process of smart urban furniture the importance of simulation based design will be discussed in this thesis as well.

Another important factor for smart urban furniture is to classify the use of the services. Various urban furniture types exist in practice today. Ranging from canopies, pergolas, carports, bus stops to benches, solar trees, street lights, and experimental objects all these structures address for certain purposes. Despite the number of urban furniture types, there is no specific research on the design and energy analysis of these structures in the literature and practice. Ignoring the design and simulation phases, results in incorrect and misleading consequences.

Not only the energy analysis, but also the architectural integrity is ignored in the design process of smart urban furniture. As seen in Figure 1.1, the architectural integration of various urban furniture is sorted according to the usage purposes (Premier, 2022). Thus, different sorts of urban furniture types, have distinct architectural integration ratios.

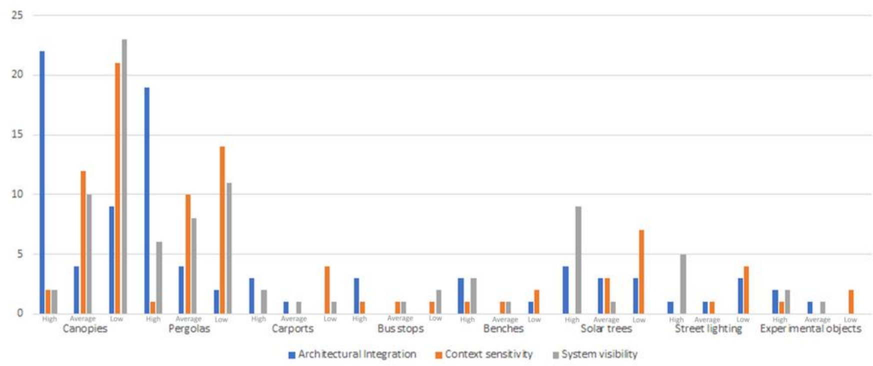


Figure 1.1. Architectural integration of urban furnitures

1.1 Problem Statement

The transition from fuels to clean energy has urged the developments of electric technology. Urban furniture is also forced to become carbon neutral. As a result, smart urban furniture concept has arisen. However, the rapid installation methods that does not take into consideration the design methodology and PV integration processes, limits the potential of smart urban furniture.

Smart Urban Furniture is the new public room for cities. Coupled with the services it provides, it becomes inevitable to address people needs in cities. All around the world city administrations place smart urban furniture for several purposes in the city. However, the design and implementation of these structures lacks analysis and site specific approach. That is, without sufficient analysis and simulation based design, proper solutions cannot be achieved. The position of the solar panel and structure, 3D Model and its shadowing and radiation related analysis should be taken into consideration. Moreover, the type of urban furniture is also a significant parameter in this research. The architectural integration, context sensitivity, and system visibility are the indicators in the design and implementation of urban furniture in cities.

Based upon the gaps that are demonstrated in the literature, the thesis research concentrates on the following research problems;

- The parameter research is insufficient in the design process of smart urban furniture. Several conditions are overlooked as a result of this deficiency. Therefore, the thesis will focus on the design science research problem.
- PV Integration in smart urban furniture is essential, since it depends on several factors, ranging from the form of the furniture to the functional and aesthetical features. As a result, this thesis aims to indicate the PV Integration process.
- The aesthetical quality of smart urban furniture is dismissed in the practical field. The fabricated SUF's lack visual concern. Coupled with the incapability of analysis based design, the smart urban furniture does not offer an aesthetical concern.

1.2 Research Questions

By identifying the gaps in the field of practice and literature, the thesis focuses on the following research problems:

- o How will the concerns of climate change affect the construction of Smart Urban Furniture?
- o To investigate, integrate, and reorganize the principles of relevant street furniture design.
- o A proper methodology for designing smart urban furniture.
- o The relationship between certain criteria and their influence on the design process.
- o The effect of the physical environment, and various formal characteristics to the urban furniture making process.
- o The Photovoltaic Panel technology and its influence on the energy generation process.

1.3 Thesis Outline

The thesis is composed of five main chapters, including the current introduction chapter. In order to respond the research questions, the thesis work touches on the following chapters of the study:

Chapter 1 (Introduction):

This chapter is the introductory part of the study, which includes the aims, objectives and research questions of the thesis research. Moreover, the chapter explains the general motivation and necessity of such a study.

Chapter 2 (Literature Review):

The literature review is one part of the research in order to examine the concept of urban furniture in cities and the historical process of it. The relationship between architecture and the concept of urban furniture will also be indicated in the literature research. Not only architecture, but also, sustainability, materiality, modularity and other factors will also be discussed in this part. The energy use and potential of urban furniture and PV panel technology are also the main concern of the literature review.

Chapter 3 (A Design Method for The Smart Urban Furniture):

In order to achieve the aim of the thesis study the design methodology and research is explained in this chapter. It can also be defined as the driver of the study. A method based on several factors including modularity, sustainability, and analysis is carried out in the design methodology process. Various options for designs based on distinct factors are created at this stage as well. For this purpose, all the design variations are modelled and simulated for the final results and analysis'. The design that indicated the best performance for various parameters is chosen for the final implementation as a result of this chapter.

Chapter 4 (Case Study):

Chapter 4 includes the proposed case studies in the field of urban furniture. The type of the structures and the general concerns in the practice and the climate analyses are categorized and demonstrated. Ranging from the use of PV technology and the size, to the modularity of designs and implementation parameters are some of the indications that is discussed and evaluated in chapter 4.

Chapter 5 (Conclusion)

Chapter 5, which is also the final chapter includes the conclusion of the thesis research. The outcomes and discussions is mentioned in this part. The studies contributions to the field of practice and further suggestions are represented to address the possible future applications.

CHAPTER 2

LITERATURE REVIEW

Urban furniture is a term that is utilized to describe the objects that are used interactively in the urban environment. For many decades, urban furniture is used in public spaces in order to represent a connection between private and public spaces. These spaces are used in order to provide people areas for resting, leisure, and multifunctional activities. “The Urban Furniture concept was born in the urban projects of the early seventeenth century, with the urbanization of the cities that was directly associated with ornamentation” (Arruda et al., 2017). The term has evolved in time and is adapted according to the needs, social and physical conditions of the cities. As a result, many transitions has the urban furniture undergone in time for further adaptations. Today, smart urban furniture concept comes to the fore, with the rise of the concern of climate change.

This chapter examines the current literature review about solar urban furniture. Smart Urban Furniture design comprises several design and implementation strategies. Therefore, it is crucial to set an understandable research outline. As a result, the examination is composed of two main parameters, which include several factors within themselves. The first one is the **General Design Requirements** which addresses to the architectural integrity of the design. The second one is the **Adaptation of the Smart Systems** which shows the integration of the smart systems to the structure (Figure 2.1).

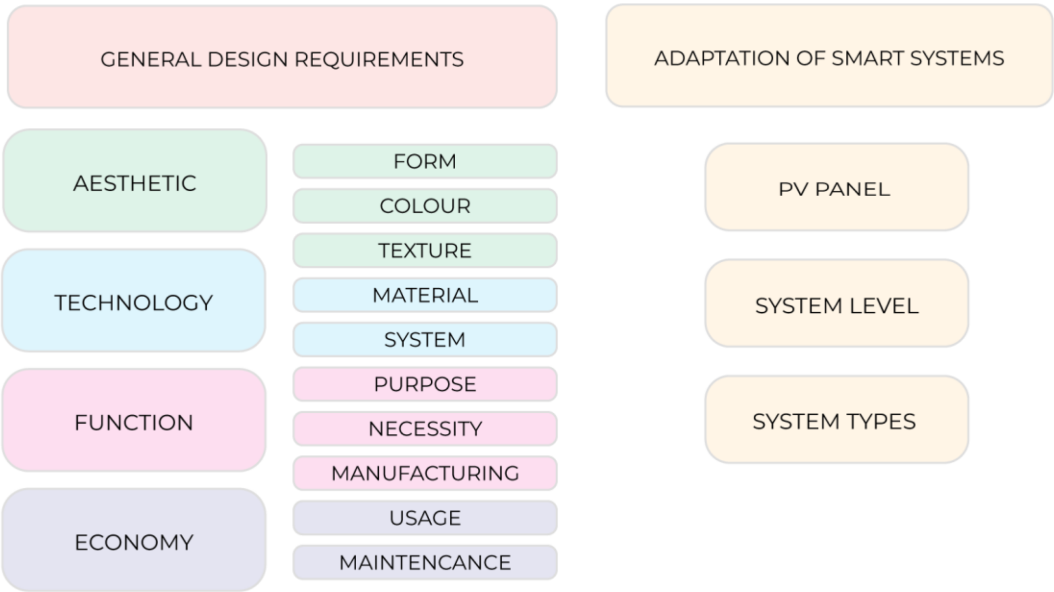


Figure 2.1. Urban furniture examination

2.1 Urban Furniture and Architecture

The term Urban Furniture is defined as "aesthetics and comfort elements that reflect the identity of a city and enable the urban space to become livable" (Bolkaner et al., 2019). Before mentioning Urban Furniture's historical process, it should be drawn attention to the use of public spaces in the past. Yücel and Kul (2021) states, "Considering the usage habits of public spaces in the historical process, the Ancient Greek agora and the Roman forum were the main political centers of the city and the spatial focus of democracy". "City squares are known as large areas reflecting the identity of the city. When the cultural dimension at the city squares is examined, transportation, infrastructure, traffic, vehicles, building and shopping centers cause such squares to lose their properties" (Bulduk,2012). The term "urban furniture" dates back to the 1960's. It was first used in Europe. It is stated "as private or public furnishings in public spaces that provide certain services and perform various public functions" (Grabiec et al., 2022, as cited in Yang, 2005). Other definition for urban furniture is defined by Cambridge Dictionary (n.d.), as the “Equipment such as lights and road signs, positioned at the side of a road for use by the public”.

> “Street furniture consists of the man-made elements of a streetscape located on the sidewalk, on a plaza, or in another type of pedestrian area. Street furniture elements are generally associated with amenities for pedestrians and they may be free standing or fixed. Included are benches or other forms of seating, bollards or posts, kiosks, drinking fountains, planters, bus shelters, information signs, trash receptacles, bike racks, game tables, lighting fixtures, phone booths and notice boards. Some authorities point to a distinction between street furniture and street hardware. The latter category refers to the utility and mechanical systems located within a street right. Of way and includes fire hydrants, manhole covers. traffic lights and signs. utility poles and lines, and parking meters” (Cartwright, 1982, as cited in Prvanov, 2017).

As Prvanov states the use of urban furniture is in places where people circulation is the most. Therefore, it is important to design urban furniture by taking into consideration the characteristics of the special context. “The elements used in the urban recreational areas should be designed in accordance with the socio-cultural characteristics of the city and the functional needs of users” (Tereci and Atmaca, 2019).

“Comfortable public spaces improve citizen’s quality of life by accommodating encounters with fellow citizens, offering recreational opportunities and considerable social and commercial value” (Spagnolo & de Dear, 2003, as cited in Peng et al., 2019). Today, cities are equipped with various kind of urban furniture that serve for different needs and contexts. Ranging from, canopies, to street lamps, or from bus stops, seats, garbage bins to road signs the industry of urban furniture has developed a lot.

The rise in population in cities has urged the diversification of urban furniture. In order to comprehend the term urban furniture better, the urban space ought to be well defined. According to Güremen (2010), “Urban spaces meet the four basic needs of the people living in it. These are work, recreation, rest and transportation”. Open spaces in cities were varied in order to respond to the needs of work, recreation, rest and transportation. Since the 10^{th} the industry of handicraft has risen and led some cities to gain their own economical prosperities. Milan, Venice and Florence were some of these cities that gained advantage. The result was the inevitable increase in commerce. The form of cities has undergone changes dramatically in a short period of time. Song and Bao (2022) states, “Until the rise of the Renaissance, the ancient Greek and Roman architectural style, urban facilities, and urban secular architecture began to revive, together with religious architecture became the new city center. Renaissance urban planning emphasized the subjective initiative of human beings and pursued the "ideal form" of cities”. The logical urban planning, and coupled with the rise of urban public in European cities urban public spaces were started to be revitalized and redesigned.

In the late 18^{th} century the emergence of industrialization in Britain opened up major changes in cities. The rise of factories has urged the need of gathering spaces in cities. Streets, parks, and squares were reconsidered and adapted to the new condition that took place in cities. Not only, major and large scale changes were made, but also the introduction of urban furniture was one major breakthrough. Street lamps, traffic lights, public transport related facilities and public seating were some of the urban furniture that were introduced to the city in that period. Water elements, shading devices, resting areas ext. were introduced as well to the people living in the cities. The use of light at night was introduced as a result of the industrialization for a response to the safety of the city. Song and Bao (2022) states, “As the area where the industrial revolution in Europe first took place, deeply influenced by the industrial revolution, the promotion of science and technology and the outbreak of productivity promoted the germination of modern design thoughts”. The industrial revolution has caused the rise of urban furniture making in a more productive and standardized manner. Many European cities incentivized the urban furniture in city squares, streets and nodes. As seen in Figure 2.2 two urban furniture examples which serve for similar needs are differentiated in their formal orientation standardized according to the context.

Figure 2.2. Bus stops in the US and Estonia

The first half of 20th century passed with great world wars that destroyed the cities. Countries planned a rapid reestablishment of cities all around the world. The improvements in science and technology boosted the revitalization of cities. It is the first time the modern urban furniture was introduced with modernized cities.

2.2 Public Space and Urban Furniture

The relation between the public space and urban furniture has always been important. Urban furniture is used for several purposes in public space such as, bus stops, resting units, garbage cans, lightings, seating, and many other services. In fact, urban furniture could be defined as the complementary elements that constitutes the public environment. “Urban furniture is a multifaceted object influenced by factors such as user needs, social structure, urban layout, geographical characteristics, technology, material, and cost” (Kaya et al., 2022, as cited in Grabiec et al., 2022). According to research on public space utilization by American urban planner Whyte (1980), “Locations with more urban furniture, especially seating, that is strategically placed are more likely to be visited”.

Public spaces are not only places for resting, and leisure but also the last developments have extended the private and working life habits to the outdoor. Laptops, smart phones and other electronic devices are used outside the offices and houses which makes outdoor public spaces working spots for people.

Public spaces indicate various characteristics for distinct contexts. Şatır and Korkmaz (2005) groups the public space as "surrounding spaces, semi-urban spaces and urban spaces). The surrounding space indicates the industrial areas, recreational spaces, farmlands that are in the outlying locations, while the semi-urban areas state the transitional area between the urban space and the surrounding space. Şatır and Korkmaz (2005) states "the space to be designed is inspected in terms of its relations with its physical environment, history, topography, its relations with the means of communication, and in terms of the locations which do not obstruct pedestrian traffic, are simple, and directly related with the needs of the inhabitants". This portrayal could be enlarged into a wider scale. The function of the urban furniture, wheatear it is temporary or permanent, the size of the public space, the developments around the environment, and the cultural backgrounds and ages of the user types could also be integrated to this interpretation.

Describing the type of context in public spaces is the key point of urban furniture organization. Parks, streets, sidewalks and recreational areas are peculiar contexts which directly influence the furniture planning process. The form, comfort and other metrics is decided based upon the conditions of the special context. A bus stop that is placed on a sidewalk requires different features than a sitting unit that is placed on a crowded city square. "Usually evaluates the street furniture alone in public space. However, it should be placed in the broader context of the city and not just as a decorative element. It is necessary to plan this criterion street furniture, paying attention to as packs of functionality, rationality and emotionality" (Creus, 1996, as cited in Arruda et al., 2017).

A well designed urban furniture does not only work as a complementary part of a public space, but it could become a symbol of the special context. “The spaces of a city are perceived through symbols and signs that manifest themselves through objects, furniture, buildings, streets, squares, signs, stairs, parking lots, among others, that make up the identity of the place” (Brancaglion, 2006, as cited in Arruda et al., 2017). Therefore, the identification of an urban furniture is only possible by taking into consideration the contextual qualification. The design parameters of the urban furniture should be compatible with the contextual integrity.

2.3 The Standardized Urban Furniture in the 21^{th} Century

The 21^{st} century brought about the rapid improvements in technology. The internet or internet of things were the main drivers of these improvements. The industrial sector, and the economic facilities were shaped drastically in this era. Inevitably cities were also influenced by these changes. Song and Bao (2022) describes the questions that were asked in this time as “What kind of city do people need? What kind of urban public living environment and urban services are needed? How do realize the fair and healthy development of cities?”.

In order to respond to the questions, many municipalities, city administrations and associations developed standardized guidelines for urban furniture that will be used in the cities. National Association of City Transportation Officials has published the Urban Street Design Guide in 2012. Many municipalities utilize from this guide book for the urban furniture planning and design, including New York City. The guide book, composed of several parts, standardizing the design used in the cities, specializing such as for small streets, medium sized streets, high speed road ext. The use of design guide standardized the making and design of urban furnitures in cities. City municipalities offered specific solutions for unique contexts, so the systematic idea of guidelines has caused a regulation for urban furniture designs. Prvanov (2019) states,

> "Street furniture, is a subject related with urban planning, urban design, planning, architectural design and industrial design. The reason of the emerging of street furniture, like the reason of the emerging of every object and physical system, is related with the formation of requirements and its historical formation process related with the development of these requirements, in time. While street furniture was produced by craftsmen one by one at first, it got industrialized due to rapid urbanization and because of increase in the need of production. Today, production of street furniture is done with mass production".

2.4 Solar Energy and Urban Furniture

"Solar photovoltaic installations are growing at a rapid pace. However, variations in solar energy distribution throughout the year and space requirements for solar PV installations pose challenges for wide spread deployment of solar PV systems" (Dey et al., 2018). The use of Solar Energy in Urban elements is certain. A lot of example exist in the urban context or in vehicles. There is a great increase in the number of patents from less than 5 in 2009 to more than 50 in 2018 (Krejcar et al., 2019).

For example, the urban context that the solar panels are implemented on, state a critical influence on the energy generation process since it might expose overshadowing effect on the surface.

Figure 2.3 shows the sun rays hitting the PV surface. With the help of simulations tools, the optimum tilt can be found so that maximum energy efficiency can be gained. In order to get the maximum benefit from the PV panel technology, the tilt angle is significant.

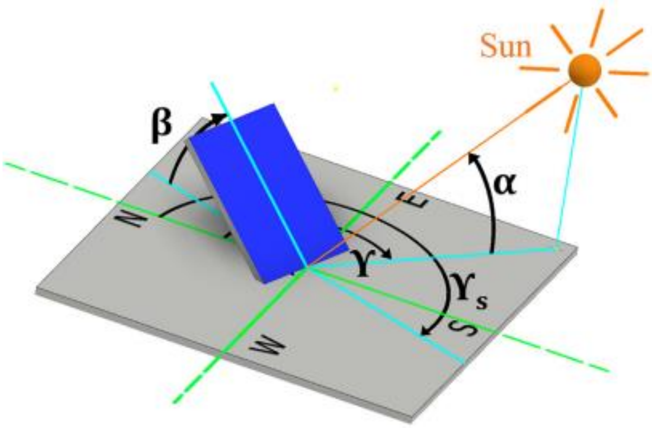


Figure 2.3. Sun angles on a tilted PV surface

The use of renewables in urban furniture design state also an imperative role. As mentioned in previous sections, the use of electricity in public spaces urged to find renewable solutions in order to supply the energy needs. Urban furniture has also evolved into a smarter position which rises the need for solar energy. “Renewable energy sources are vital to meet the energy demand of the future with solar photovoltaics being one of the prime sources due to abundant availability of solar energy” (Dey et al., 2018).

2.5 Urban Furniture Examples

The case studies that are explained in this section represents some of the successful examples of smart urban furniture designs. The PV installation, modular variation, and several parameters are taken into account while choosing these case studies. Kaya et al. (2022) classifies the criteria for urban furniture into the following parameters;

Production	Location	Material	Form	Unity
Ecology	Function	Infrastructure	Use	Site Selection

Although there are lots of factors that directly influence the smart urban furniture research process, in order to clarify the case studies, the criteria that are mentioned above could easily help to determinate the case studies that would be explained. As a result of the classification of the criteria, the smart urban furniture examples are chosen based on this parameter set.

2.5.1 Fluid Cube and City Snake

The Fluid Cube and City Snake is a smart urban furniture that is located in Hungary designed by and architectural office. The structure is composed of two separate pieces that can be connected to each other. This provides a modular advantage to the furniture. The structure is designed for the public use as well as use in the schoolyards. It can be described as a bench with technical services. The first part of the structure is the 9-meter square main cube itself. It works as a shelter for people passing by in bad weather conditions. As indicated in Figure 2.4, two parallel bench encompasses the main cube. These are called The City Snake, a 7.5-meter outdoor bench that is curved in various directions in order to provide sitting options and positions. Both the Fluid Cube and City Snake is integrated with PV panels in order to produce power for services they offer. The main cube is installed by solar cells and the city snake seating are installed with conventional solar panels.

Figure 2.4. Fluid Cube and City Snake connection

The solar panels generate power for the USB charging outlets, the Wi-Fi hotspots, as well as the benches’ lighting systems. For people traveling the city, it is important to have access to electric chargers and other services.

Another important equipment is the wooden material that is used in the structures. It is important to prevent cracking of the wood. Therefore, in order to prevent this, joints were implemented in between the wooden layers. Moreover, the modular structure that combine all the pieces together is another advantage for the installation and usage. It enables various connection options to the specific context on which it is implemented on. The fluid cube is designed opened on two opposite sites in order to line up more than one unite side by side.

The use of wood in the urban furniture refers to the context, which is an area that wood is used as a common structural element. Coupled with the fact that, the geometry of the smart urban furniture is adaptable to the school yard, accentuates the sensitivity of the context based design decisions.

On the other hand, the modularity of the structure increases the site specific functionality of the urban furniture (Figure 2.5). The form of the snake shaped modules could be easily integrated to the main body.

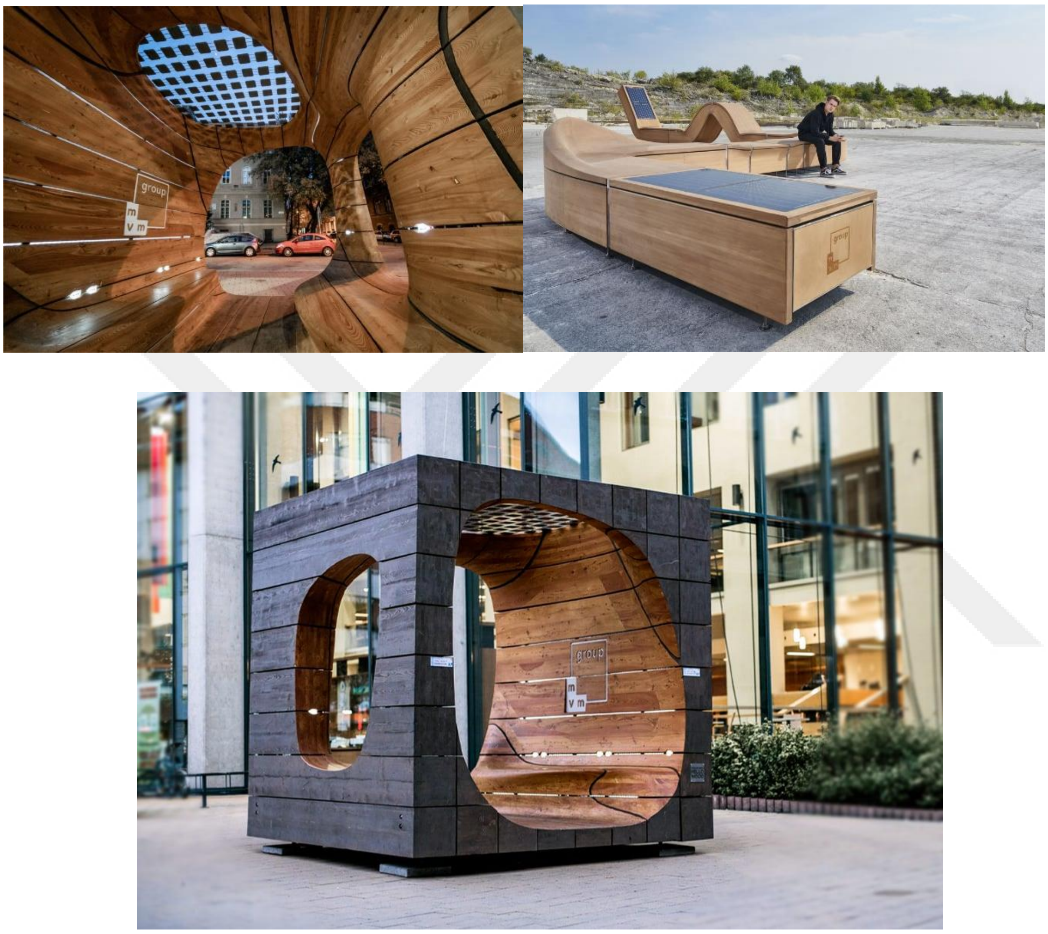


Figure 2.5. Fluid Cube and City Snake modules

In the production stage a lighting system, usb outlets and solar panels and batteries were implemented to the design. The material application was convenient as well. By using CNC technology wooden pieces, that are made of larch, were cut from sawn blocks. It was successfully managed to design a structure that would fit in the CNC machine without generating waste.

2.5.2 Solar Pavilion by V8 Architects and Marjan Van Aubel Studio

The Solar Pavilion is an exhibition that is built on a city square in Eindhoven. It was designed and built for Northern Europe’s largest design event. The curved sheets of solar panels and four metal steel supports comprises the whole structure.

The festivals theme for the year was “Get Set”. The architecture firm collaborated with solar specialists in order to design a public place which would please people and gather around. The pavilion is composed of three main spaces in which people can experience and observe the glass PV panels transmitting sun rays through itself. The design also enables visitors to visit and investigate the solar panels on the rooftop. The structure is made intentionally practical in order to be implemented and set quickly for the exhibition. The wire, connections and other supports are visible as a part of the design strategy. The exhibition could be defined as a solar panel field which provides a peculiar atmosphere to the users. The wires that are tensioned between four steel supports carry the solar panels.

This example is located in a crowded public space in Eindhoven, highlighting the assembling function of street furniture. The sitting units in the structure enables to gather around people around the site. In this sense, the function of the SUF coincide with its surrounding. Coupled with the PV panel experiential roofing system as seen in Figure 2.6, the SUF does not only work as a resting space for people, but it becomes an exhibition space. This example accentuates the variation of usage of smart urban furniture.

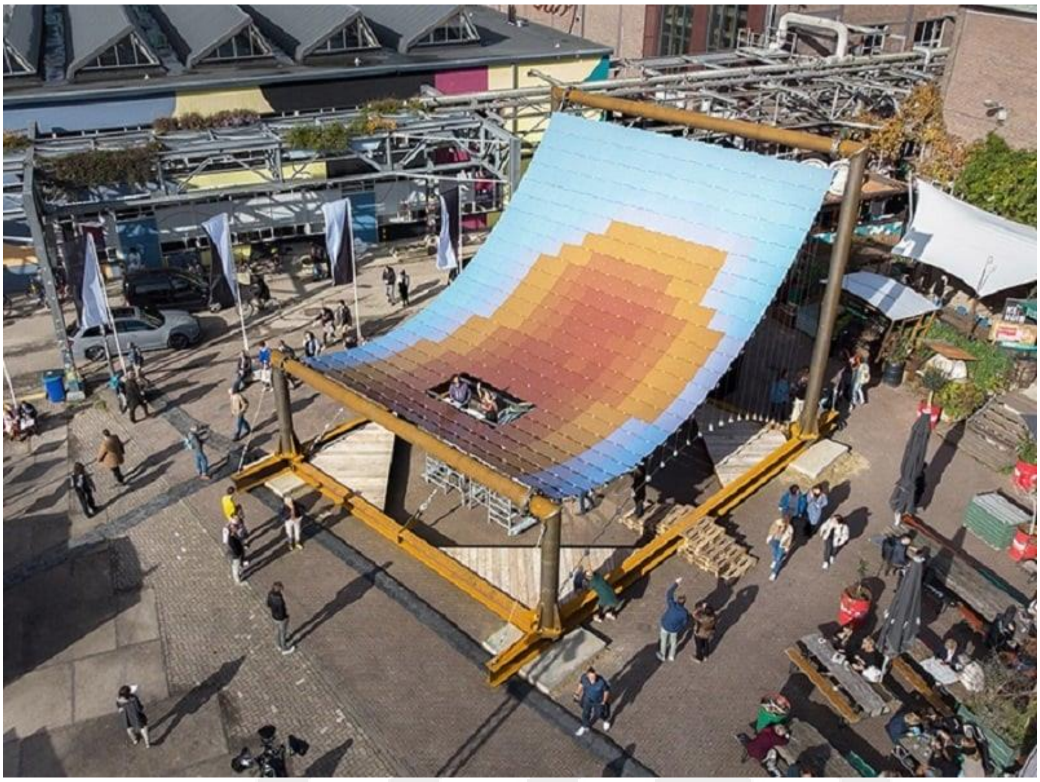


Figure 2.6. Solar Pavilion

“The panels produced approximately 7.5 kilowatts of energy at peak performance while on display at the design event, according to V8 Architects” (Peacock, 2022). The energy that is created would transmitted to the on-side battery system. The battery system enables lighting and electric heating in the pavilion. "Currently, energy is only harvested in a techno-functional way, we explore how to integrate the sun's energy into our daily lives so that we can love and embrace it” (Raaphorst, n.d., as cited in Peacock, 2022). The pavilion is intended to be disassembled so that the materials from which they are gathered would return again to the suppliers. There are three main structural and spatial parts that the visitors can experience.

- The Solar Field
- The Alcove
- The Circle

As indicated in Figure 2.7, the three main parts is identified. The common feature of these parts is to work as a gathering space which assembles people around. Thus, the experience of the energy harvesting process is the main aim of this gathering space.

Figure 2.7. Solar Pavilion at night

2.5.3 Solar-Powered Trees for Cool Spots in Public Hot spots

Cities are places which the temperature is higher compared to the suburbs because of several reasons. One of them is the extreme heat gain in the pavements and walls of the buildings. “The world’s cities are heating up at twice the global average rate due to rapid urbanization and the urban heat island effect. By 2100, many cities across the world could warm as much as 4°C if GHG emissions continue at high levels” (UNEP & Cool Coalition, 2021). As a result, a Japanese consortium has decided to design an urban furniture that responds to the rising needs of cooling spaces in open public spaces.

As seen in Figure 2.8 respecting the contextual value of the region, a wooden structure is designed in order to provide people a resting space, with cooling service. The structure could be described as a “cool spot”. The basement is 4.8m x 4.8m while the roof is 4m x 4m in dimension (Nikken, 2020).

Figure 2.8. Wooden Smart Urban Furniture in Japan

Using wood as the primary material, it causes a compatible design orientation with the special context. Coupled with the fact that wood is easy to recycle, and easy to form, it makes the design orientation appropriate with the criteria that are mentioned above. Since the furniture is positioned on a crowded spot in the city center, the design differentiates itself in between the concrete structures.

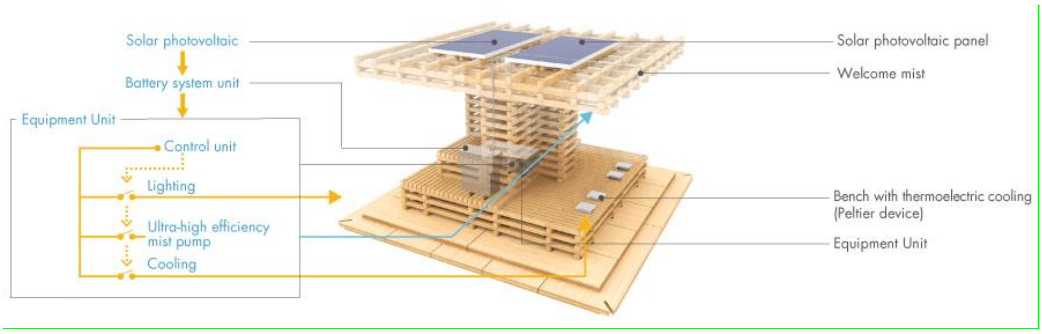


Figure 2.9. Functional diagram of the wooden urban furniture design

As indicated in Figure 2.9, the PV panels that are implemented on the top of the structure directly feeds the energy needs of the cooling apparatuses that are hanged under the roof. The cooling equipment directly blow water vapor on the users that are sitting below, which results in a freshening effect. Coupled with the sun shading roof, the users are not directly hit by the sunrays.

Nikken (2020) states, “The wooden structure can be repeatedly assembled and disassembled by joining together each of the parts with bolts only”. Thus, the formal organization could be arranged in order to provide opportunity for various conditions and context.

As a result, the solar powered tree could be described as a successful example of a smart urban furniture, which takes into consideration several criteria, which constitutes a holistic design approach for the context.

2.5.4 AKTINA – New Productive Urban Furniture

The smart urban furniture Aktina is located in an old industrial area. It is an off-grid power station which harvests solar power in order to charge e-bikes, as well as other mobile devices. Since the site, which the urban furniture is set is an old industrial area, the smart urban furniture formal and material solution is intended to be compatible with the surrounding. As a result, the formal organization of the smart urban furniture, represents an industrial approach. The PV panels are placed in a manner which do not hide itself. Moreover, the cables which transmits the energy from the panels into the services below are represented to the users. As seen in Figure 2.10 the simple organization addresses to the context itself.

Figure 2.10. Aktina Smart Urban Furniture

Not only the formal organization, but also the material selection represents a simple approach. The use of wood and steel in the design organization allows functional flexibility. The cubes that are placed on the bottom part of the furniture are independent elements which allows to be rearranged according to various needs.

Since the site which the urban furniture is set into could not be described as a crowded public area, the lighting that is used under the sitting units, is intended to increase the sense of safety in the dark. The usage of the urban furniture is to represent a recreational pavilion which comprises storage boxes which work as well as vegetation pots. The storage modules could also be used for sitting purposes. The multifunctional use of independent elements allows various formal combinations. As seen in Figure 2.11 the spatial organization is indicated below. The cubes could be put on top of each other in order to arrange the sitting position for different user groups. The modular organization of the cubes opens up the smart urban furniture to the context it is placed on.

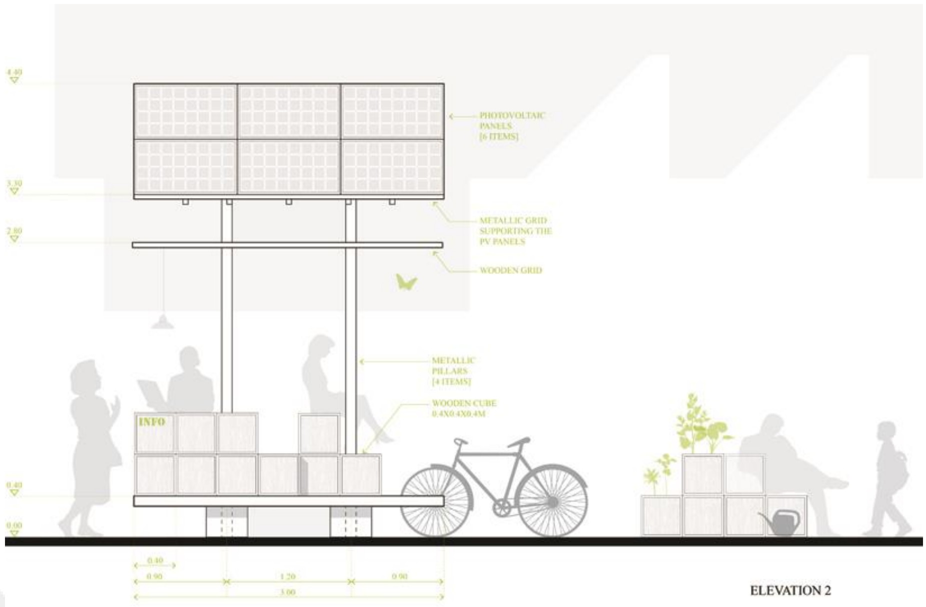


Figure 2.11. Spatial organization of Aktina Smart Urban Furniture

CHAPTER 3

A DESIGN METHOD FOR THE SMART URBAN FURNITURE

Chapter 3 presents the development and structure of a method for the smart urban furniture. Smart urban furniture design process is not well defined in the market and practice. The industrialized fabrications are seeking to provide services that could be integrated to each condition. However, the design parameters and methodologies are ignored. As a result, in this chapter it is intended to generate a methodology for smart urban furniture design that puts the process into standards.

The design method seeks for structuring a new way of designing smart urban furniture, based on certain parameters in two main stages. The first stage is the design science research, which includes the data gathering process. The second stage is the Urban PV integration process. In this phase, the PV panel technical requirements are discussed and searched.

This method comprises several inputs including 3D modelling, which creates a baseline for environmental analysis's and enables a more comprehensive understanding of smart urban furniture design alternatives. The analysis of human outdoor comfort, which informs about the comfort zone of the users in certain time periods, helps for the arrangement of the design and directly influences the design stage. While analyzing outdoor comfort, total radiation analysis is simultaneously investigated in order to apprehend the reciprocal relationship between each other. One think that has been taken into consideration is the technical requirements for services (including battery usage, and dimensions for spaces. The requirements for electric scooter battery charging units and other facilities state an important role for the design stage and energy simulations for responding the needs. While paying attention to the parameters, the modularity for design alternatives, and the material selection for smart urban furniture design, is imperative. The alternative usages for various contexts and needs and responding them is another aim of the study. Therefore, the methodology comprises the modularity as well. The smart urban furniture will serve for various uses including charging stations for scooter, or studying spaces which will charge laptops and smart phones. The use of PV panels and getting proper and maximum energy efficiency is important for these services. Therefore, the PV energy efficiency analysis is another part of the methodological process. Mentioning all these parameters and calculation processes the architectural concern is the complementary part of all these sub-topics.

As part of the thesis study, five main design alternatives is developed according to various design criteria. These design alternatives are presented to the İstanbul Municipality for decision making. In Table 3.1, the design methodology is indicated based on two main stages, which are explained briefly in the first section.

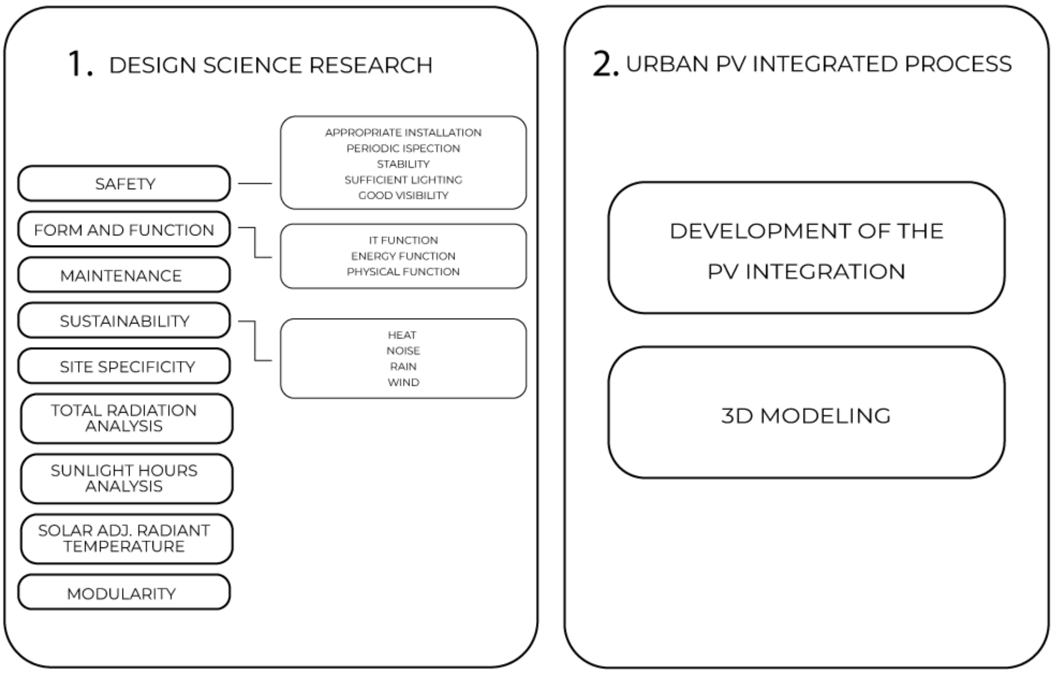


Table 3.1 Design Method

The first stage comprises the design method criteria, which would define the base for the case studies. The parameters define and directs the result and endpoint of the case studies and design method.

3.1 Design Science Research

The design science research is essential in terms of gathering data. While designing smart urban furniture, collecting the right parameter set is critical. In order to obtain the proper factors that would influence the design phase, the literature and the practical solutions state an important role. The design science research process starts with the identification of the design problem. The problem would define the framework of the research. Based on the needs that would be described in the first section, the definition of the objectives of the solution comprises the second stage. The indication of the objectives helps to describe the needs of the research process. This stage is a problem and context centered initiation for the design and development process. This stage is a reciprocal relationship between definition of objectives and the identification of the problem. As seen in Figure 3.1 the design science research process indicates several stages for the development of a smart urban furniture (Azasoo and Boateng,2015).

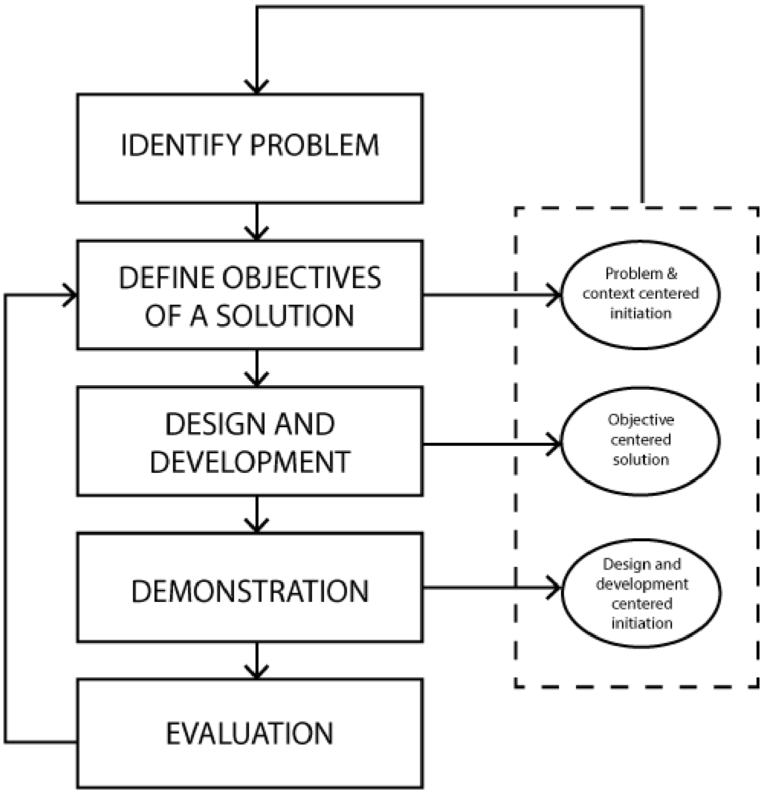


Figure 3.1. Design Science Research process

The design development is the process in which a product is proposed as a result of the identification of the problem and objectives. The design and development stage comprises the design method criteria which would be explained in the upcoming sections. After the design and development stage, the demonstration of the end product is acquired. After this process the evaluation stage is developed. The evaluation stage is a constant check phase, which works interactively with the definition of the objectives. The fulfillment of the objectives could be checked in this phase. As a result of the evaluation process the design science research process ends with the communication stage. This stage is the constant revision of the design development, based on the feed backs that come from various commons.

3.1.1 Design Development Process

The design development process consists of several criteria that are interconnected into each other in a complex relationship. As mentioned in the previous sections, the criteria that builds up the design and development process are inevitable elements that directly influence the working of a smart urban furniture. Based on the indications of the criteria, the flowchart that is demonstrated in Figure 3.2 indicates the design development process in a hierarchical order.

Thus, five criteria are chosen as primary objectives, which are; safety, maintenance, site specificity, sustainability, and form & function. Based on these main parameters, the solar adjusted radiant temperature, total radiation, sunlight hours analysis, and modularity comes as the secondary stage of the design development. The parallelogram shapes indicate the preliminary criteria that constitutes the primary and secondary stages.

The flowchart (Figure 3.2) assists also in order to set a hierarchy between the criteria and enables proper decision making process while two or more parameter sets contradict with each other.

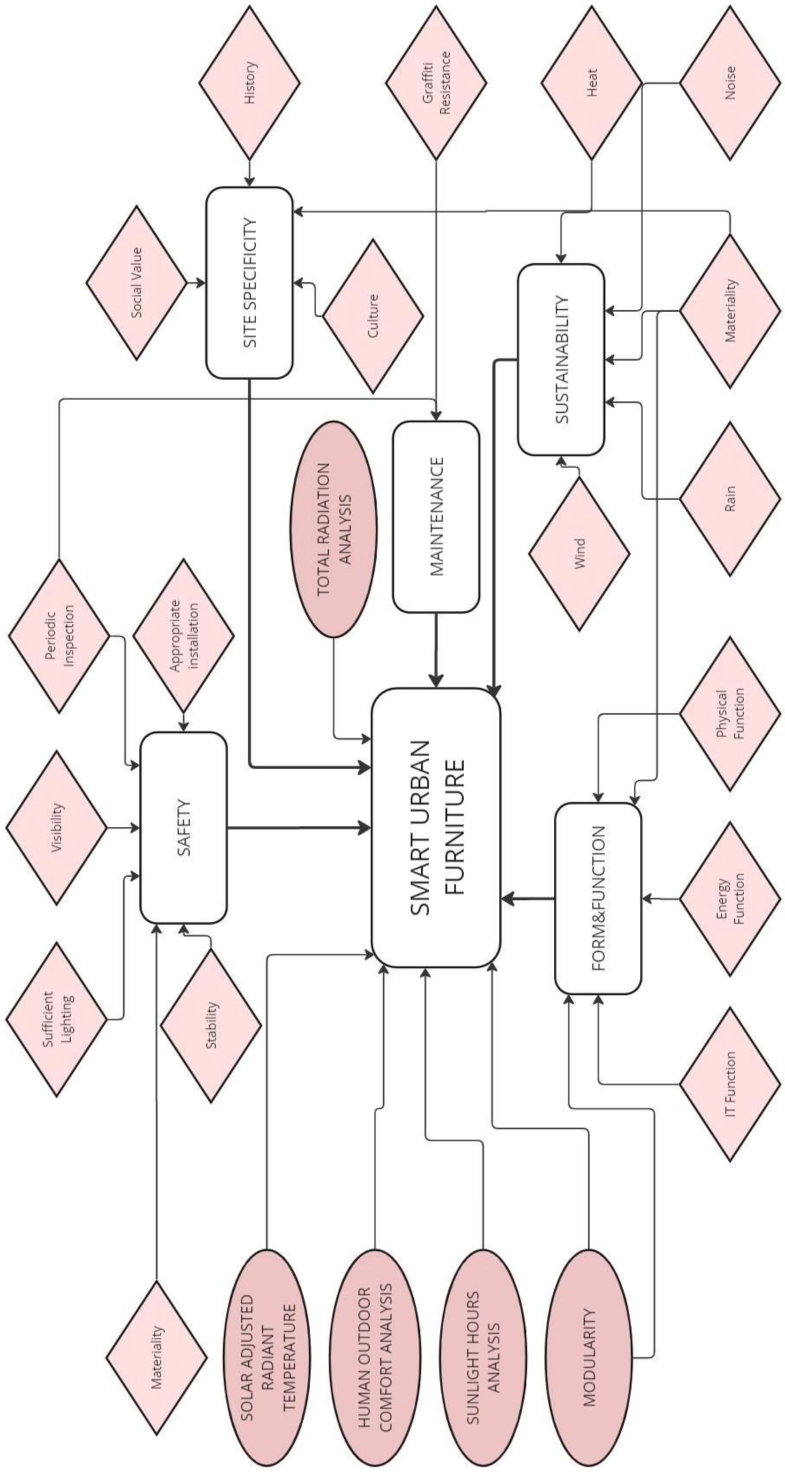


Figure 3.2. Design Development Flow Chart

To begin with, while starting to design, **safety** is an imperative parameter that would directly influence the process. Without, taking into account the safety precautions any design could not be considered as successful and usable. Safety comprises a lot of sub-factors that directly affect the design process. Appropriate installation, periodic inspection, stability, sufficient lighting, and good visibility are some of the parameters that have a significant influence on safety for the SUF design. Khan et al. (2021), categorizes the difference between smart urban furniture and traditional furniture regarding safety parameters as (Figure 3.3);

CRITERIA	**Smart stop**			**Traditional stop**		
G-Good P-Poor F-Fair	**G**	**P**	**F**	**G**	**P**	**F**
1.SAFETY						

Appropriate Installation			x	√		
Periodic Inspection			x			x
Sufficient Lighting (2 - 5 Footcandles)	√				x	
Locating Bus Stops Near Existing Streetlights For Indirect Lighting	√				x	
Stability	√			√		
Durable Linkage Elements	√				x	
Good Visibility		x		√		
Avoid Planting Evergreens	√			√		
Vegetation that Stands Above 1.8-2.1 m, and Lower than 60-90 cm	√			√		
Locate Stops At Highly Visible Sites	√			√		

Figure 3.3. Safety difference of Smart Stop and Traditional Stop

Form and Function is another parameter that come into the fore in the design methodology process. This parameter comprises also the aesthetical concern which the smart urban furniture seeks. Taking into consideration the safety precautions that are explained in the previous page, the form and character is structured based upon this. “The multi functionality of urban furniture, resulting from the innovation of solutions, is ideal for small spaces” (Grabiec et al., 2022). Premier (2022), classifies the function in smart urban furniture into three,

- IT (Information Technology) Function
- Energy Function
- Physical Function

These functions could be sub-grouped as;

IT Function; Wi-Fi hotspot, visual information, audio information, advertising, remote management system, video surveillance, monitoring (pollution, transport, people movement)

Energy Function; Electronic device charger, e-bike charger, e-scooter charger, e-car charger, energy harvesting

Physical Function; Protecting, resting, shading, heating, cooling, working, lighting, parking, advertising

The functions that are indicated above, directly influence the formal organization of the smart urban furniture. In order to provide a comfortable space for cooling functions for instance, the physical form should be arranged accordingly. On the other hand, the functional requirements and features directly affect the PV integration process. The PV integration process would be mentioned in the upcoming sections.

After indicating the safety and functional phases, **maintenance** is another important parameter that directly affect the design stage of smart urban furniture. Urban furniture are prone to vandalism, the smart urban furniture design ought to be resistant for the actions that would destruct itself. Therefore, furniture inspection, graffiti resistance, and easy cleaning are some of the factors that comprise the maintenance parameter.

Sustainability is another parameter that would constitute the main design methodology. It includes several sub factors, such as durability, resistance, material, and technology. While mentioning sustainability, the first stage is the simplicity of the design methodology. Thus, designing with minimum materials, avoiding decorations, multi-functionality, and modularity could be described as simplicity concerns of designing smart urban furniture.

Durability is one of the factors that comprise the sustainability parameter. Khan et al. (2021) categorizes durability in 4 sub-groups;

1) Heat
   a) Use of non-metallic benches
   b) Light colored materials reflect solar rays more than darker colors
2) Noise
   a) Barrier walls should be considered in order to avoid noise
   b) Site furniture should be placed towards entertaining sources
3) Rain
   a) Benches should discharge water accordingly
   b) The material should be mold resistant
4) Wind
   a) Positioning sheltering furniture from strong prevalent wind
   b) Providing wind screen

Material is another important factor that directly affect the sustainability parameter. Selection of the material in smart urban furniture design is essential since it influences the heat, noise, rain and many factors directly. Moreover, choosing the right material is important in order to establish a longstanding smart urban furniture design.

Technology is also related with sustainability. Since smart urban furniture aims at generating energy in order to respond the needs of smart services, technology states an important place. Energy generating, device charging plots, e-bike charging units, and several other services are a concern of technology factor within the sustainability parameter.

Total Radiation Analysis

One of the design parameters in smart urban furniture is the total radiation analysis. It enables to understand the radiation efficiency of a structure. Especially for smart urban furniture design, this analysis enables to comprehend the total radiation's possible effects on thermal comfort. While maximizing the total sun rays hitting the PV panel surfaces in order to generate electric energy, the users comfort rate should not be underestimated. Excessive amount of radiation rate, might constitute a discomfort for the users that are resting or sitting on the smart urban furniture. The total radiation analysis could be used in order to understand the solar head gain or could be used for PV panel analyses. In order to calculate the radiation of outdoor spaces this component could be used. The radiation could directly affect the thermal comfort which is essential in urban furniture design. As seen in Table 3.2, the parameters that directly affect the radiation results are indicated.

Table 3.2 Input – Output Radiation Analysis

Input Parameters	*Output Analysis* *Radiation Analysis*
Geometry	Radiation Result
Context	Total Radiation
Sky Matrix (Including the weather data)	
Mean Radiant Temperature	
Analysis Period	

Sunlight Hours Analysis

Using sun vectors from the sun source, this analysis type determines how many hours the geometry receives in direct sunlight. This type of analysis can be used to determine how many hours of sunshine, plants in urban furniture receives, or it can be used to determine whether or not direct sunlight makes an outdoor location comfortable. This analysis also conveys the relationship between sunlight hours and total radiation analysis results. The analyses that influence the sunlight hours results are made by utilizing the parameters in Table 3.3.

Table 3.3 Input – Output Sunlight Hours Analysis

Input Parameters	*Output Sunlight Hours Analysis*
Geometry	Sunlight Hours Results
Context	Total Sunlight Hours
Sun Vectors	
Grid Size	
Distance from Base	

Outdoor Solar Adjusted Temperature Calculator

In this analysis, the quantity of direct and diffuse sun radiation falling on a comfort figure is calculated using either of the Radiance functions. These direct and diffuse radiation numbers are used to calculate the portion reflected off the ground and into the comfort figure. This analysis helps to comprehend the surrounding environment on users on a detailed scale. The Table 3.4 indicates the parameters that affect the outdoor solar adjusted temperature.

Table 3.4 Input – Output Outdoor Solar Adjusted Temperature Analysis

Input Parameters	*Output Solar Adjusted Temperature*
Location	Mean Radiant Temprature
Diffuse Horizontal Radiation	
Temperature	
Horizontal Infrared Radiation	
Context Shading	

Modularity

Modularity could be described as; a type of combination in which a group of elements are combined in different ways, in various forms. Modularity provides designers a sense of flexibility while designing. It gives the freedom to the design to be fit or placed in several locations and spaces. As mentioned in Chapter 2, modularity could be grouped in various subtitles. Independent or group modular units could be used as the design methodology. In this sense the modularity is an important design method that would be used in this thesis research.

In urban furniture design, it is significant to represent various connection combinations for distinct conditions and contexts. Placing a fixed and stable furniture to the context does not provide flexibility and adaptability for the users. Benches, tables and panel modules could be arranged on their own or could be combined to each other, which provides a basis for improving social interaction. Below the Figure 3.4 is an example of modular design variations that could be suited and fit in different conditions for distinct purposes and dimensions.

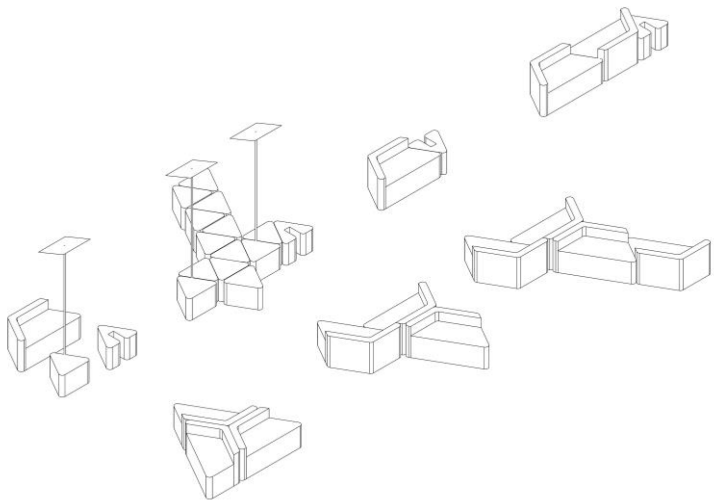


Figure 3.4. A modular design example

Not only the system adaptability, but also maintenance for urban furniture state an important role. Proper installation of materials and parts guarantee the strength for the structure, so that the maintenance is possible for further applications. Modularity enables also replacement with sustainable products when the technology provides cleaner solutions. Designing the furniture with interchangeable modular pieces would make it easier to repair and prevent it from being unusable for extended periods of time while repairs are being done.

It should also be drawn attention to the problem of vandalism. In cities items that directly belong to the urban life, could be exposed to damages. Urban street furniture is continuously vandalized by burning, breaking, painting and other destructive methods. While choosing applicable and durable materials, another important method for sustaining the street furniture in the context is modularity. Substitutable components provide an economic solution for vandalism. The whole structure would not be replaced, only the damaged parts could be repaired.

Concrete Printing

3D Printing is started to be used widely in urban furniture production. Thanks to its practical way of constructing, it enables shorter use of time in manufacturing. While conventional and traditional concrete structures are larger in size, this type of construction technique provides thinner forms for concrete structures. Therefore, this inevitably provides more design options. Since, the thickness of the concrete can be diminished to 2cm, it brings about the opportunity of flexibility as well.

However, this new technology brings about some shortcomings, which is lack of design alternatives with respect to conventional steel frame structures. Whereas, steel frame structures provide various design alternatives in terms of strength, 3D concrete printing technique may not present much freedom in design and forms. While constructing, the concrete is released by a tube which squeezes the it vertical to the ground. Without any other support structure, the sole concrete structure may not be sufficient enough for the realization of the design. The Figure 3.5 indicates the working principle of a 3D concrete printer.

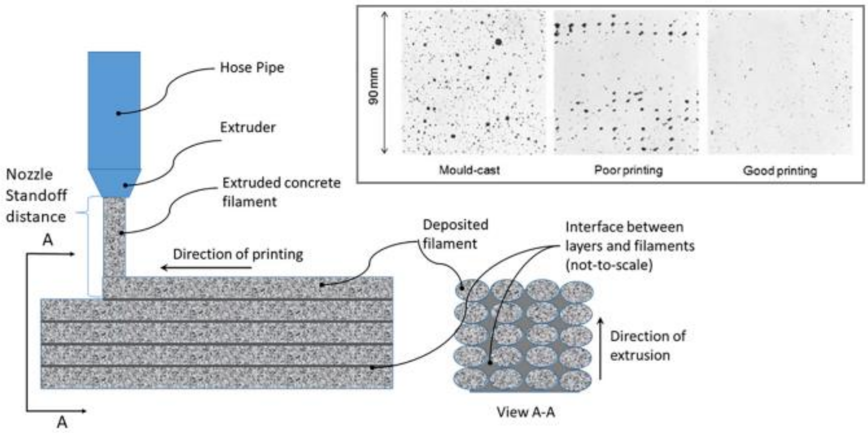


Figure 3.5. 3D concrete implementation

Implementation

Several precautions should be taken into consideration. One of these is the solidity and durability of the urban furniture while being exposed to vandalism.

Therefore, after meetings with the fabrication team, five main alternative designs were decided as incompatible with the implementation method. The fluid concrete that is going to be blown to the ground would not stand the geometry that all of the alternatives required. Therefore, a new method of making the urban furniture is needed. As explained above, the implementation of 3D printing technology provides a planar and sectioning method for constructing. As a result, the main body of the urban furniture is shaped according to this way of making.

The advantage of 3D printing is to provide faster fabrication while problems such as design freedom comes as a significant deficiency to the fore. Drastic changes in the geometry has the impact of instability and breakability on the main body. Also the structure has to be printed in certain dimensions in order to fit in the printing machine. These dimensions might change, but numbers range from two to three meters.

PV Integration

PV panels supply clean energy for several services in buildings, public areas, urban uses and many other sectors. As mentioned in Chapter 2: Literature Review, PV panels could be placed and fit into many fields. The increasing technology also enabled PV panels to be improved and enhanced. In this sense the PV panels are integrated with building facades, agricultural fields or vehicles. Thus, PV technology provides users various options. As a result, in the design method, choosing the right and proper PV installation and integration is essential. As the criteria for PV integration the list and parameters could be reached in Table 3.5 This table comprises four main PV panel types which are classified by their specific features including efficiency rate, cost, weight, dimension and power. Cerón et al., (2013) classifies PV integration as; appearance and composition, support and dimensions, shape, use of elements and purpose. The purpose of the use, state a great importance in the decision making process of PV integration.

Table 3.5 Input – PV integration parameters

PV TYPE	PARAMETERS
Concentrated PV Cell	Efficiency Rate
Monocrystalline Solar Panels (Mono-Si)	Cost
Thin Film Amorphous Silicon Solar Panels	Weight
Polycrystalline Solar Panels (p-Si)	Dimension
	Power

3.2 Urban PV Integrated Process

After the design science phase, in which the parameters are searched by reference sources, the Urban PV Integrated process is the second stage of the design methodology. As a result of the requirements and parameter research the proper PV integration would be conducted based upon the design science research phase.

Development of the PV Integration is based upon certain sub-factors. Tereci and Atmaca (2020), categorizes the integration into four main parameters;

1) Aesthetics
    a) Form, Color, Texture
2) Function
    a) Purpose, Necessity, Conformity
3) Technology
    a) Material, System
4) Economy
    a) Manufacturing, Usage

In this stage, first of all, the solar energy is calculated based upon these factors. The functional requirements taken from the design science research section specifies the PV infrastructure. After fulfilling the specifications, the radiation analyses that would be carried out help to calculate the solar power of the specific site for the specific design. The final stage comprises solar adjusted temperature analysis which evaluates the neighboring materials influence on the users. As a result of these calculations the PV integration is developed. In the development of the PV integration there are three main phases;

- The visual impact of the PV system
- The positioning of the smart urban furniture
- The infrastructure of the PV system

CHAPTER 4

CASE STUDIES

The case studies are designed and analyzed according to the parameters that are listed and detailed in Chapter 3. There are six main case studies that are studied in this thesis research. As mentioned in the previous sections, the thesis research concentrates on the design and implementation of a smart urban furniture. In order to realize this process, several factors and parameters are mentioned in order to clarify the development of the urban furniture. General requirements and parameters are stated, including the environmental analyses, material selection, modelling development and modularity, ext.

The thesis research, is a reflection of a study that is planning to realize a smart urban furniture design and sustain the implementation of this structure. For this reason, five main alternatives are developed as a result of this research and process. These design options carry the same features in terms of prerequisites. Therefore, the optimum calculation, and design is not the intended concentration and result of this study.

The general requirements for the design alternatives is to design an urban furniture that will respond to the needs of electric energy needed services, and feed its energy by solar panels. The urban furniture is intended to be consist of three main modules addressing distinct aims.

- Table: The use this module is to provide a space for studying and charging the electric demanding devices.
- Bank: The use of this module is to provide a resting area for people while, supplying electric energy for smart phones ext.
- Storage: The use of this module is to offer people a room, for their personal goods, used as a depot that ensures personal security.

As a result, the design alternatives focus on three main features that are strutured as modules allowing several combination opportunities.

4.1 Context: Kadıköy Square

Although the boundaries of the square are not definite, roughly the area between Haydarpaşa Train Station and Kadıköy Metro Station is considered the square. The square contains the Kadıköy Platforms, from which buses depart to all parts of the Anatolian Side except Şile. Coupled with the ferry station that the Kadıköy Square hosts, the area welcomes crowds who use this region for transportation.

Not only as a crossroad between transportation routes, but also Kadıköy Square has a cultural and historical value as well. Haydarpaşa Station, and Kadıköy Pier are structures which date back to the late ottoman and early republican period. As a result, Kadıköy Square could be defined as a special place which gathers historical, cultural, functional and social values together.

4.2 Design Science Research

The Design science research conducted for 6 of the case studies would be explained in this section. The beginning of this process is the identification of the problem. This process is shaped upon the context and problem centered initiation. After this process a common objective is decided in order to create a solution for the research problem. With the goals set, is the design development built based on the flowchart outlined in section 3. The design development is an objective centered solution for the problem that is identified in the first stage. As a result of this stage, the demonstration of the design development is intended to be fulfilled. The evaluation process is an interactive process with the second stage: The objective centered approach. Finally, the communication process completes the design science research phase.

4.2.1 Problem Identification

The research identifies the problem with the guidance of the context. The study area is a crowded crossroad where people interaction and traffic is intense. The place is used by people from various ages and social groups. The students, working groups, elderly group and many other profiles use this area. Especially, people wait for their ferry and buses and spend time in this area. As a result, this brings about a need for resting and studying within this waiting period.

Moreover, the rising use of internet and electronic devices, urged the needs for e-chargers outside. As a result, this place deprives of a network system which initializes the ease for electronic device usage. In addition, the open space in front of Kadıköy Port is exposed to direct sunlight, and creates a discomfort for users. This is another problem that the context requires a solution for.

4.2.2 Definition of Objectives

Based on the problems that are explained in the previous section, the main objective of this section is to state a systematical way of designing a Smart Urban Furniture that responds to the need of the problems that are identified. Firstly, the SUF ought to be create a resting space for the users, as well as constituting an area for studying. Moreover, the SUF should contain services for electronic devices as depicted in the problem identification stage. Coupled with the rising use of e-bikes, there should be generated an energy amount which responds to this services. In addition, the resting space should be compatible with the climatic conditions of the specific context.

4.2.3 Design Development

The design development at this point is shaped by the method outlined in Chapter 3. The primary framework for this stage is the flowchart that is referenced in the title of the design development process.

4.2.4 Demonstration

The end product of the smart urban furniture for 6 of the design alternatives are demonstrated in the demonstration phase. The modular organization and other physical and aesthetical features could be evaluated based on this stage. Six design alternatives are formalized as a result of the design development phase.

4.2.5 Evaluation

The evaluation stage denotes the phase in which the design alternatives are assessed. The evaluation process has a reciprocal relationship with the design objectives. Wheather the objectives are achieved or not, could be assess in this section.

4.3 Alternative 1

Alternative 1 is composed of three modules as it is stated in the previous sections. The general design understanding is derived from an elliptical shape that could be arranged in distinct combinations. Although, the use of circular shapes is difficult for modular design, the method of cutting the ellipsis from its straight parts, enables combinations possible. As shown in Figure 4.1 the general design is composed of two main materials in the outer skin. The inside of surfaces is covered with wood material, whereas the outer envelope is composed of an aluminum composite panel shell.

Figure 4.1. Alternative 1

The dimensional features are open for PV panel installation on the top of the structure. In addition, the closed roof structure state a shading effect for the users, while supplying thermal comfort as well. The further analysis's and explanations are presented in the upcoming sections about the calculations and simulations. The place where the structure is implemented is a location in which shading context is not existing.

4.3.1.1 Safety

The two sided open shape of Alternative 1 increases the dialogue of the user with the public space. Therefore, it constitutes a sense of safety with the wide openings on both sides. However, the inside of the smart urban furniture should be supported with lightning in order to preserve the safety conditions in lack of sunlight.

The middle module of the smart urban furniture, which is also explained in the modularity section, is an inclined structure which would state a danger while being exposed to outer interventions. Therefore, a counterbalance should be fit in order to ensure safety precautions of the smart urban furniture.

4.3.1.2 Form and Function

The formal organization of the first alternative is a closed elliptical shape. This provides an enclosed area at the top of the smart urban furniture, which enables a space for PV panel integration. The elliptical shape is divided into three main parts, which are used as table, bench and storage space.

The functional requirements of the smart urban furniture could be indicated as; e-bike charger, electronic device charger, Wi-Fi hotspot, protecting and resting. Another functional requirement is decided in the safety section which indicates lightning as another requirement. The inclined separators between each module provides a comfortable recumbence surface for the users. The roof is arranged %2 sloped in order to carry out water drainage successfully.

4.3.1.3 Maintenance

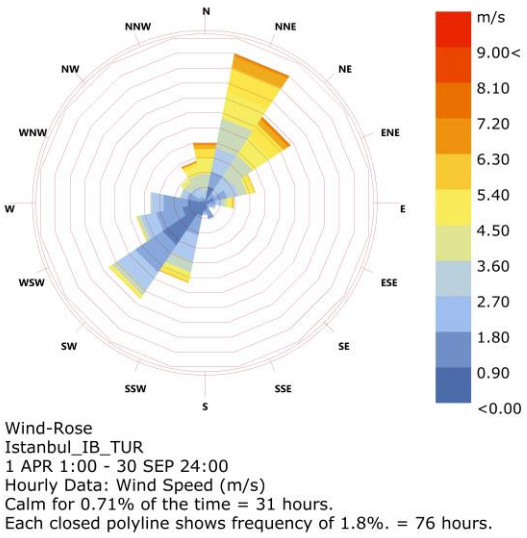
Wooden material is used in the inner surfaces of the smart urban furniture, while the outer skin of the structure is covered with composite material. Wood is a material that does not transmit the heat directly to the user; however, being exposed to water and humidity results in deformations and decay in the material. As a result, the wood is chosen as impregnated and implemented accordingly to the surface. This avoids fast deteriorations in the form of the seating and inner structure.

4.3.1.4 Sustainability

As explained in chapter 3, the smart urban furniture should be respond to the needs of heat resistance. Therefore, nonmetallic benches are used in order to refrain overheating problems in the sitting surfaces. The second parameter that is explained in the design methodology section is the noise factor. In order to refrain noise in smart urban furniture, the modules which serve for distance purposes are separated with barrier walls, which also work as the connection surface of separate modules. Coupled with the middle module, that works as a storage space, the noise level is decreased to a certain extend.

As stressed on in the previous title, the rain is another important factor that should be taken into consideration. Therefore, the outer skin is covered by composite material which resist to water and humidity. Coupled with the %2 slope in the roof structure, the water could be successfully being discharged.

Another important input that directly influence as mentioned in chapter 3 is the wind factor. Each location has its own climatic conditions. Since the case studies would be implemented in Istanbul, the conditions of Istanbul ought to be taken into account. The rose chart of Istanbul in two periods are indicated in Figure 4.2. This chart utilizes to the placement of the smart urban furniture in the proper direction.



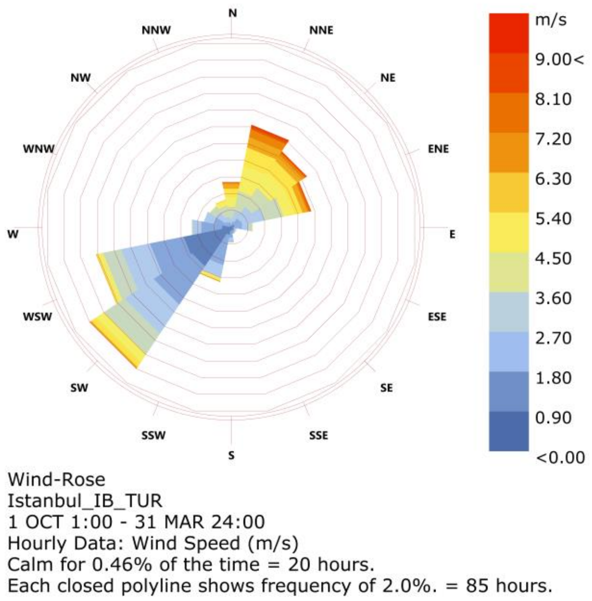


Figure 4.2. Wind Rose Chart

As indicated above, in warmer periods the wind hits from the northeast direction, whereas in colder periods the wind hits from the southeast. It could be understood from the rose chart indicated above, that the structure should resist at least 10 m/s wind speed.

4.3.1.5 Total Radiation Analysis

The Figure 4.3 indicates the total radiation results for April and August. As demonstrated the red color denotes the higher value for radiation rate. For the alternative 1, the surface which evolves itself as the roof on the top constitutes a shade below, which enables a lower level of radiation to hit the sitting surfaces. In August the total radiation result is 605 kWh while in April the value is 475 kWh.

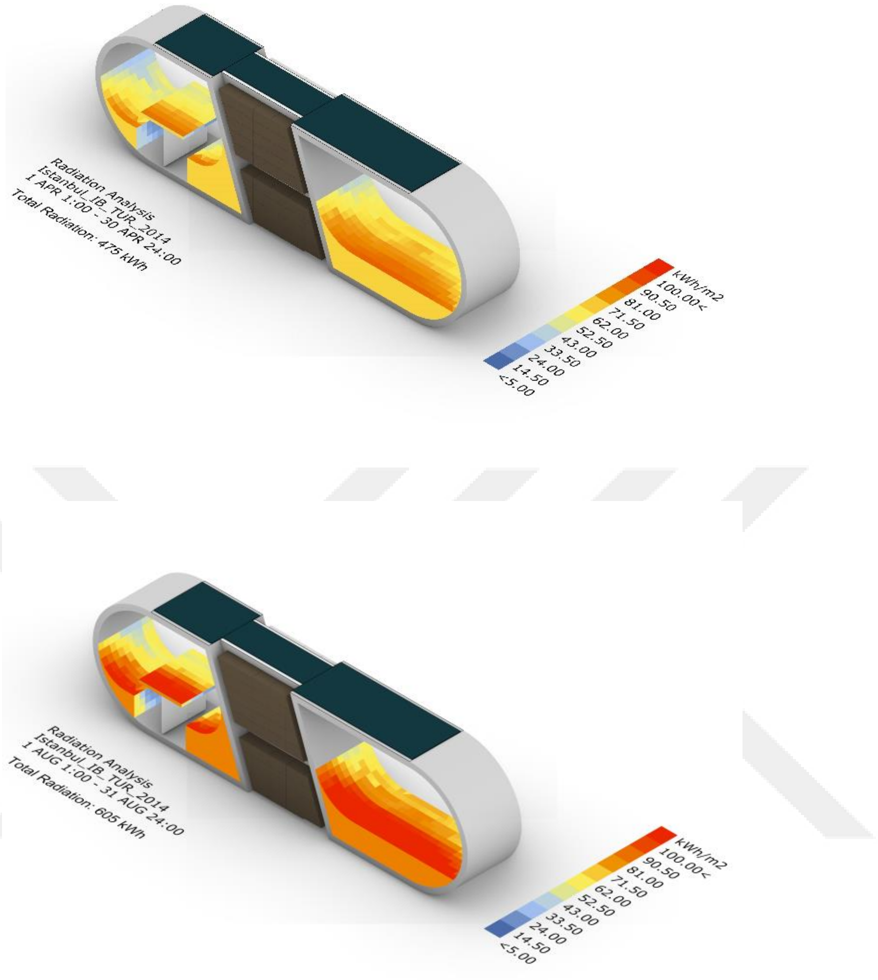


Figure 4.3. Total radiation analysis for April and August of Alternative 1

4.3.1.6 Total Sunlight Hours Analysis

The total sunlight hours analysis indicates the duration of sunrays hitting a surface in a specific timeline. As indicated in Figure 4.4, the sunlight hours in April hitting the sitting surfaces is 1438 hr, while in August the value becomes 1418 hr.

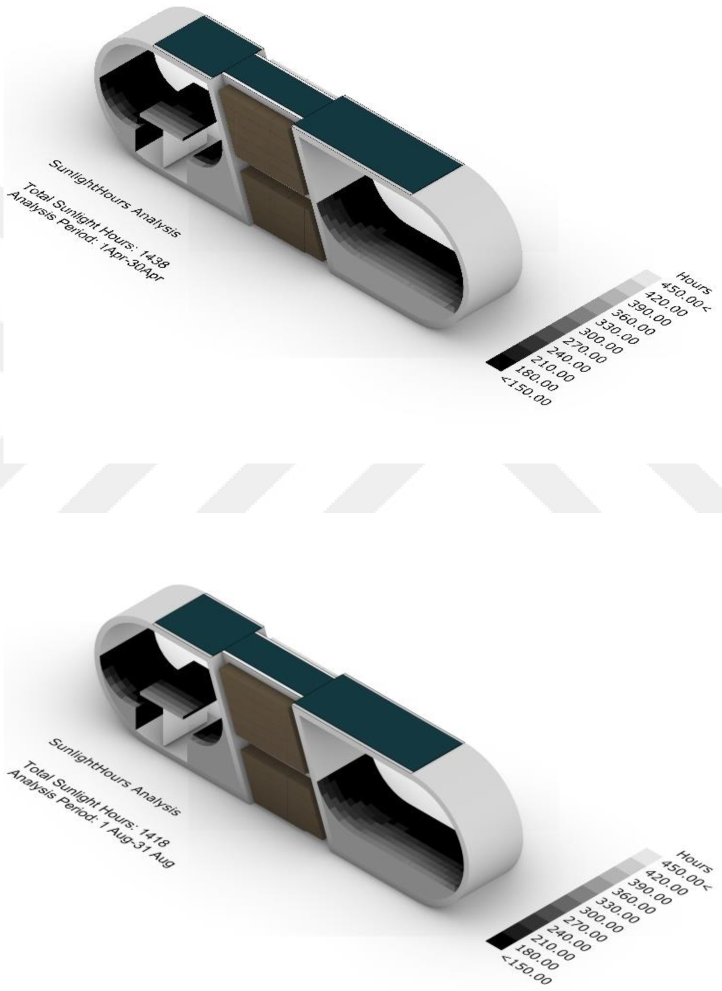


Figure 4.4. Total sunlight hours analysis for April and August of Alternative 1

4.3.1.7 Solar Adjusted Radiant Temperature

As shown in Figure 4.5 the first analysis result indicates the radiant temperature without any shading element. As seen the tip points of a human figure absorbs higher radiation amount, whereas in the second figure the human is placed under the urban furniture alternative 1. As a result of the shading effect of the structure, the overall temperature map changes. The second human figure absorbs less radiant temperature compared to the first figure which is placed on a location without any context shading element.

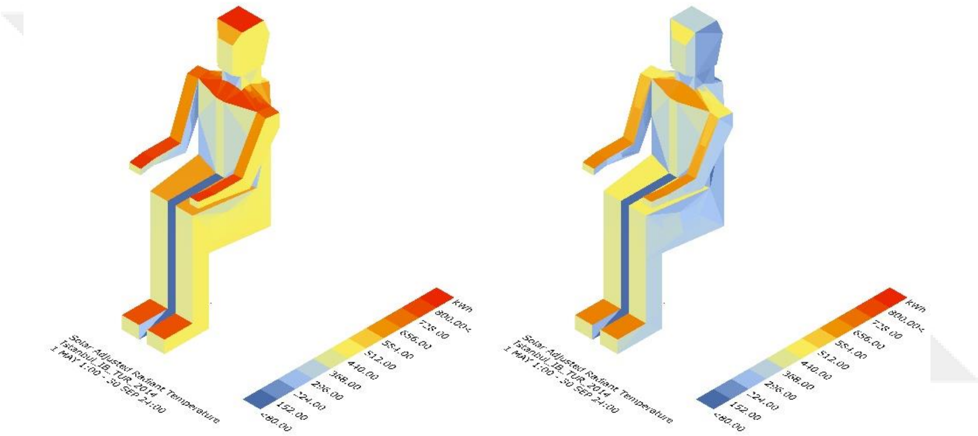


Figure 4.5. SART analysis from May to Septembr of Alternative 1

4.3.1.8 Modularity

The first alternative is composed of three main modules which work separately. As seen in the Figure 4.6 the modules could be combined in different variations. Since each module works for different purposes, the modularity provides combination variations for any conditions. As seen below, while the storage module could be used with the table module, it could also be used with the sitting module. If a lot of storage space is needed, the storage modules could be connected to each other as much as required.

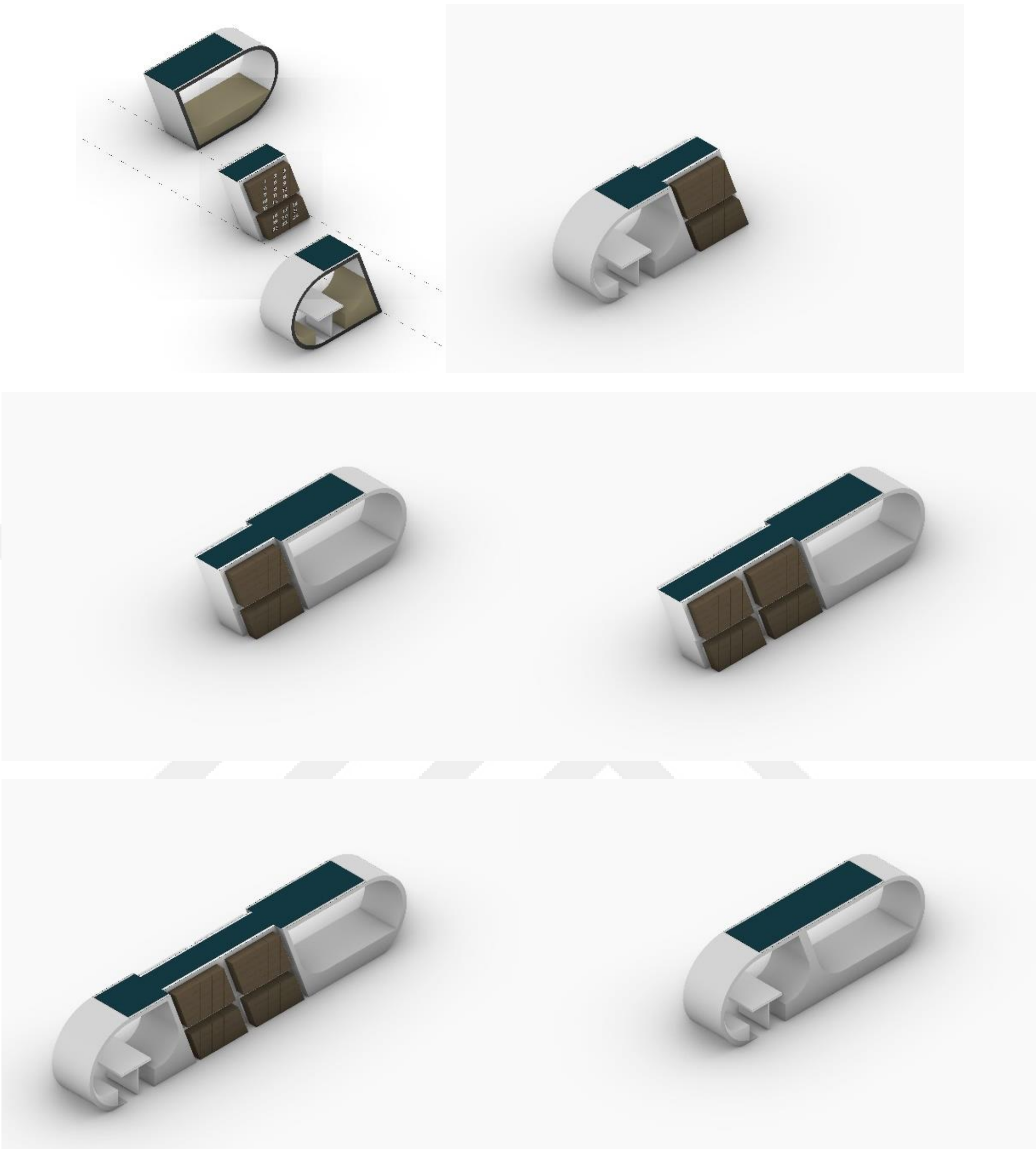


Figure 4.6. Modular variation of Alternative 1

4.3.2 Urban PV Integrated Process of Alternative 1

The area of the PV panel for Alternative 1 is 3.76m². 0.96m² of the PV area feeds the table module, while the 0.8m² PV panel feeds the storage and the 2m² PV module generates electricity for the sitting unit. The PV system is flat shaped, and implemented on the top of the roof structure. Therefore, a curvalinear PV module could not be integrated on the roof, such as Concentrated PV cell (CVP) or Thin Film Solar Panels. As explained in Chapter 2, the parameters for the proper PV Integration are;

- Efficiency Rate
- Cost
- Weight
- Dimension

Since there would be a storage unit in order to recharge the batteries of e-scooters, there would be an energy need of 200-500 W. As a result, since Monocrystalline Solar Panels are more efficient than Polycrystalline Solar Panels, the PV system could be run by monocrystalline solar panels. Although the cost is higher in monocrystalline solar panels, the energy need for e-scooter could only be met.

The PV integration depends on four main factors. As mentioned in chapter 3, these factors are; aesthetics, function, technology, and economy.

First of all, the monocrystalline solar panel is aluminum framed. Secondly, the outside of the PV system is covered with tempered cover glass in order to provide safety conditions mentioned in the first stage. The third phase is to place the encapsulation foil, which holds the solar cells together on both sides. The fourth phase is the monocrystalline solar panel placement process. The back of the solar cells is protected with encapsulation foil, which are also protected with back sheets. Under the PV panel frame, would be the junction box located. The junction box is the element where the cables are interconnected with the PV panels.

Since there are three main modules to be served, the PV panels are divided into three different parts, which serve independently to the module they are connected to. Thus the electric cables are installed separately into the modules.

4.4 Alternative 2

Alternative 2 is also composed of three modules responding to the same conditions and requirements that is mentioned above. The general design understanding envisions a perpendicular design orientation that enables various connection combinations for each module. As displayed in Figure 4.7 the general design is composed of two main materials in the outer skin. The outer and inner surface are composed of wood, whereas the contour lines that follows the continuity of the overall structure is accentuated with aluminum composite panel material.

Figure 4.7. Alternative 2

The top of the smart urban furniture is closed in order to open up room for PV panels, which work for energy supply to the chargers that are installed below. Just as the first alternative there are three modules which are table, bank and storage. These, modules could be combined in different organizations, which enables flexible solutions in different contexts for distinct needs.

4.4.1.1 Safety

Alternative 2 is a semi-closed structure which is covered with a roof structure that provides protection to the user below. In order to preserve the safety conditions, the smart urban furniture is supported with lightning in the edges of the seating. The perpendicular shape of the structure ensures stability, which avoids an additional counterbalance weight to be implemented.

4.4.1.2 Form and Function

The formal arrangement of Alternative 2 is a perpendicular shape whose services provide a sitting space, table area, and a storage space for users. The horizontal roof structure enables room for PV integration services.

The functional requirements of the second alternative are demonstrated as; e-bike charger, electronic device charger, Wi-Fi hotspot, protecting and resting. The seat dimensions and back supports are arranged in order to provide comfort to the users. The seat dimension is arranged as 50cm in depth, while the sitting units are not back supported which would result in discomfort while entering into the module.

4.4.1.3 Maintenance

The conditions of maintenance in a smart urban furniture is essential. The explanation of capability of maintenance is discussed in chapter 3. Easy interchangeability, and cost effective solutions are the main drivers of the maintenance parameter. The outer surface of the smart urban furniture is implemented in wood. The convenient cleaning capability of this material, coupled with the cost effectiveness, it brings this material as a preferable element. Moreover, the thermal conductivity of wood is 0.1 – 0.2 W/mK, which could be classified as low, so it does not create discomfort to the users in terms of heat. The outer skin is impregnated which provides resistance to graffiti paint.

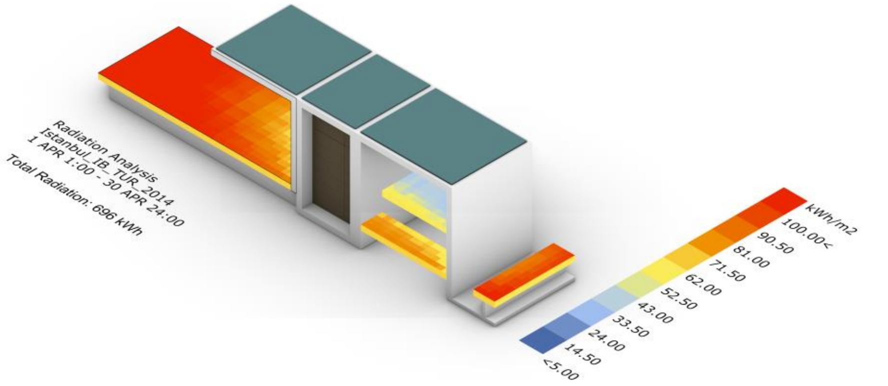
4.4.1.4 Sustainability

In order to abide by the principles of sustainable design, simplicity is one of the key stones in this alternative. The clear form of the smart urban furniture provides to construct with minimum materials. The modularity is another important factor that would be mentioned in the upcoming stages.

Refraining from heat gain is also important in the sustainability parameter, the total radiation is calculated in the total radiation analysis section, which brings about information about the thermal comfort of the users. The perpendicular elements, constitute a wind barrier to preserve the users, while the flat roof is %2 inclined in order to evacuate the rainwater from the roof. The table unit is enclosed in two sides which protects the users from noise coming from the surrounding environment, while the sitting unites are open to the public.

4.4.1.5 Total Radiation Analysis

The total radiation analysis that is calculated for April and August, shows the difference between two months below. While the sitting module is exposed to excessive amount of radiation the table module which is enveloped with walls and the takes less radiation compared to the other modules. As seen in Figure 4.8 with the color blue the least radiated region is the table module.



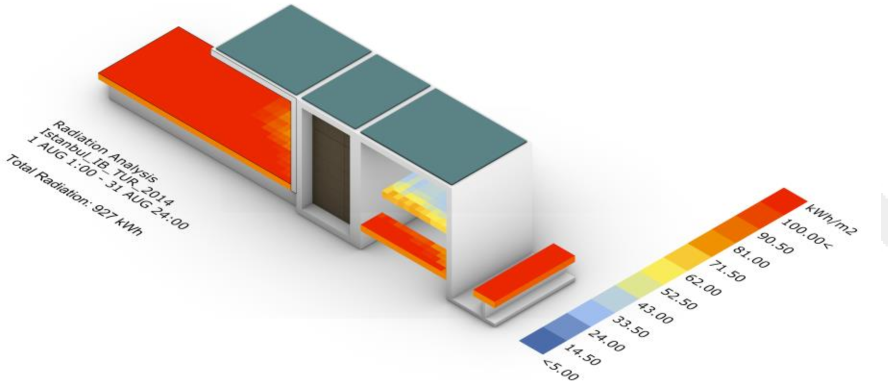


Figure 4.8. Total radiation analysis for April and August of Alternative 2

4.4.1.6 Total Sunlight Hours Analysis

The Figure 4.9 indicates the sunlight hours analysis that is calculated for April and August. With respect to the analysis results of total radiation, the sunlight hours graphic resembles to the radiation map. The sunlight hours in April is 2115 hr, whereas the number is 2207 hr for August. In terms of the overall results, the graphic does not directly coincide with the total radiation analysis results. However, the map shows a resemblance with the radiation graph that is indicated above.

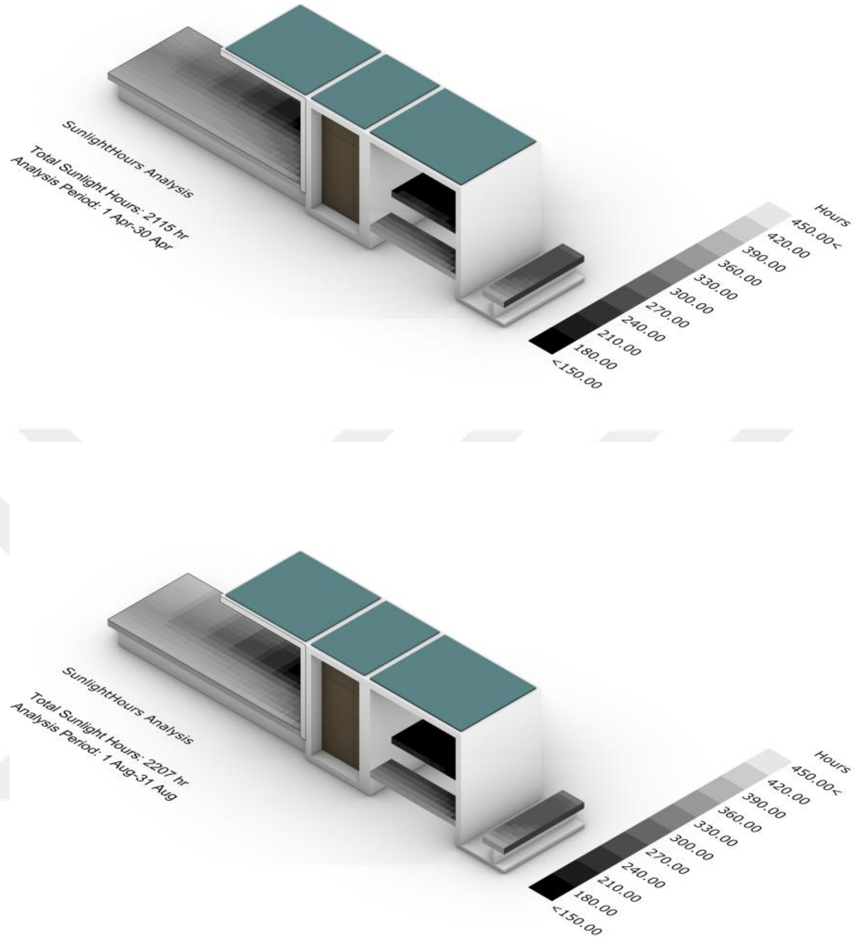


Figure 4.9. Total sunlight hours analysis for April and August of Alternative 2

4.4.1.7 Solar Adjusted Radiant Temperature

The solar adjusted radiant temperature results are shown in Figure 4.10. Since the figure is placed under the sitting module which has a vertical shading element on the right, the results show that the right part of the human figure has less radiant temperature compared with the left part. Therefore, while the left part constitutes a discomfort for the figure especially in summer months the average calculation that includes the months between May and September shows the difference between two sides of the human body.

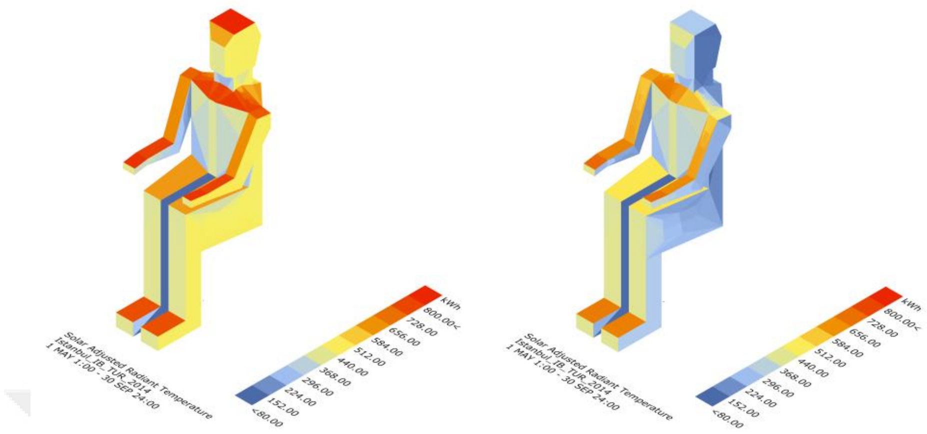


Figure 4.10. SART analysis from May to September of Alternative 2

4.4.1.8 Modularity

There are three different modules, as indicated in Figure 4.11, which works as storage, sitting and table components. The middle element works as the binder. The perpendicular geometry does allow several variations of combinations. Whereas the first alternative has a curvilinear shape which makes it difficult for modularity, the perpendicular angle of the modules creates better combination alternatives. While each module could be used separately, the storage could be placed in between the side modules, which creates a linear modularity which could be enlarged as much as possible.

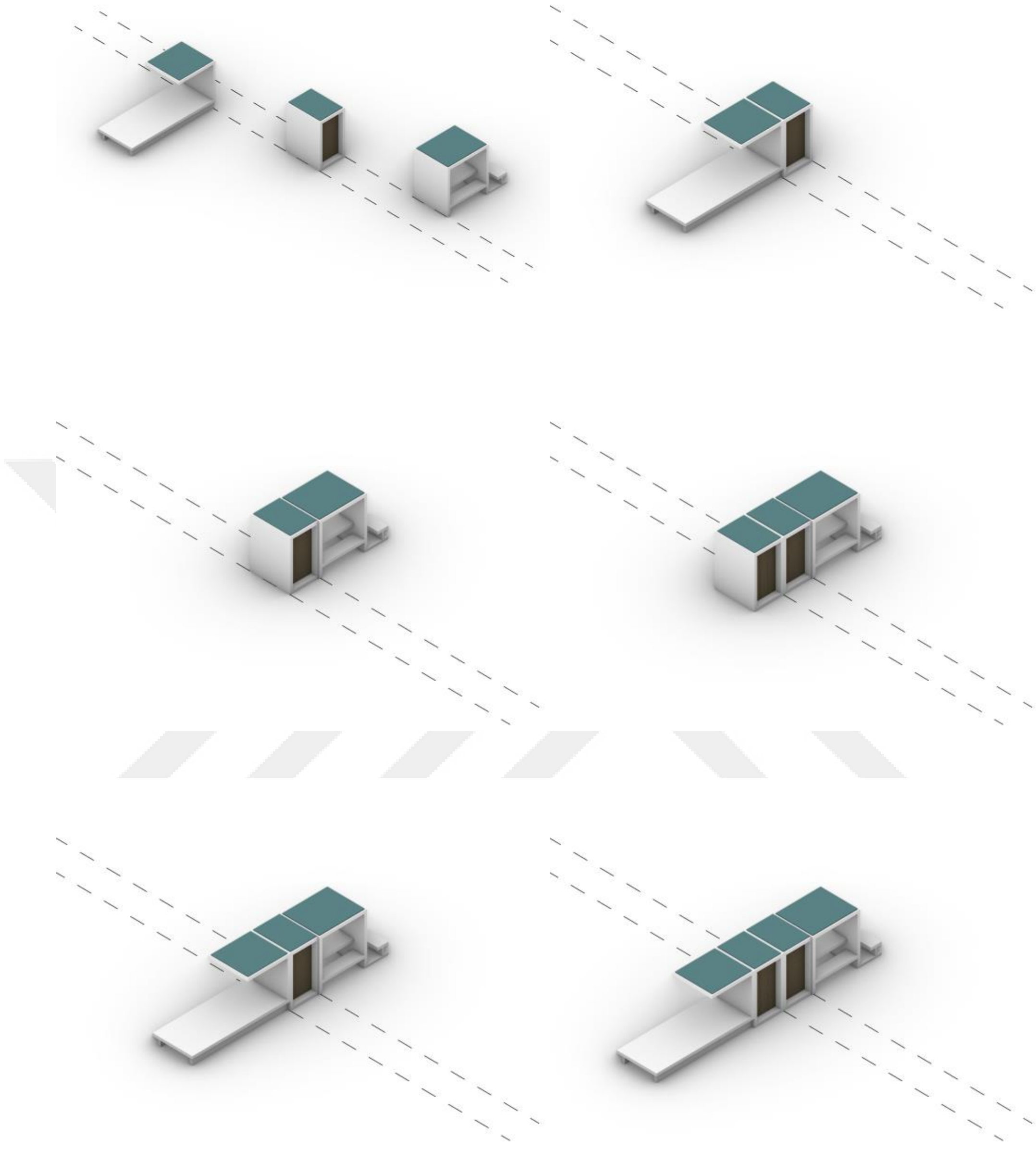


Figure 4.11. Modular variation of Alternative 2

4.4.2 Urban PV Integrated Process of Alternative 2

The area of the PV panel for Alternative 2 is 5.90 m²;

- Sitting unit PV area: 2.1 m²
- Table unit PV area: 2.4 m²
- Storage unit PV area: 1.4 m²

Resembling to the first alternative, the second alternative is a flat roof smart urban furniture. As a result, concentrated PV cells could not be the optimal solutions regarding the physical form.

Since there would be a storage unit in order to recharge the batteries of e-scooters, there would be an energy need of 200-500 W. Moreover, the smart urban furniture would also serve as Wi-Fi hotspots, and electronic device chargers. An electronic device charger needs approximately 5 W, while the Wi-Fi hotspot requires an energy of 10W to 20W.

The PV panel is aluminum framed. The solar cells are covered with tempered glass which is a resistant material against collisions. Moreover, there are three different junction boxes for three separate modules in order to provide separate energy transition for modules.

4.5 Alternative 3

Alternative 3 is a curvilinear structure that is combined with three spate modules. Unlike other design alternatives that are explained in the previous part, the table functioning module is placed in between the storage and bank module. Since the triangular form of the storage module is unable to connections on both sides it is shifted to the edge of the urban furniture. As seen in the Figure 4.12 the general material selection is composed of wood and aluminum composite panel. The wood material that is used on the surfaces that people will directly touch, does not distract human comfort since it is a The top of the structure is semi closed in order to provide a shading effect for the users, as well as presenting room for the PV panels that will be placed on. The dimensional and technical features will be explained in the upcoming sections.

Figure 4.12. Alternative 3

4.5.1.1 Safety

The inclined shape of Alternative 3 resembles to the first alternative. The design requires a periodic inspection in order to provide safety conditions. The storage units are electronic registers that protect the goods that are placed inside. Moreover, in night times the smart urban furniture is illuminated with lightings. This create a sense of safety for the users, when people circulation is lower.

4.5.1.2 Form and Function

The functional organization of alternative 3 could be grouped into three. The physical function is to provide protection, as well as serving for resting and represent shading for human comfort. The IT function of the design alternative is to store elements that people place into the storage unit with electronic registers. The last function responds to the energy needs, including electronic device charger and e-scooter charger.

4.5.1.3 Maintenance

The maintenance capability of alternative 3 is directly related with the convenience of the use of the smart urban furniture. The material is selected as wooden on the surfaces that directly touches the human skin. Since the thermal conductivity of wood is 0.1 – 0.2 W/mK, it does not create discomfort to the users in terms of heat. Wood and composite material are easily interchangeable which becomes an advantageous feature for maintenance conditions.

4.5.1.4 Sustainability

Alternative 3 is designed could be described as a simple structure which does not include decorative purpose materials. The furniture size could be indicated as reduced into the level of standards. Coupled with the modular design principles, it could be integrated in various needs and conditions.

Another important parameter is the heat effect. The roof structure that covers the sitting unit does not totally enclose the surface underneath. As a result, the positioning of the smart urban furniture should be positioned so that the roof would constitute a shading effect to the users below. Moreover, the use of light colored materials reduces the heat gain of the surfaces.

4.5.1.5 Total Radiation Analysis

The radiation results for Alternative 3 is shown below. Compared to the Alternative 2 the radiation results draw a similar mapping. Since the design area is less than the second alternative, alternative 3 absorbs less amount of radiation in total. In April the radiation amount is 619 kWh, while this number is 835 kWh in August. It is understood that the radiation results coincide with the average temperature of the months. As seen in Figure 4.13 the middle module, the shading effect of the side surfaces create an envelope and reduces the amount of radiation hitting the surface.

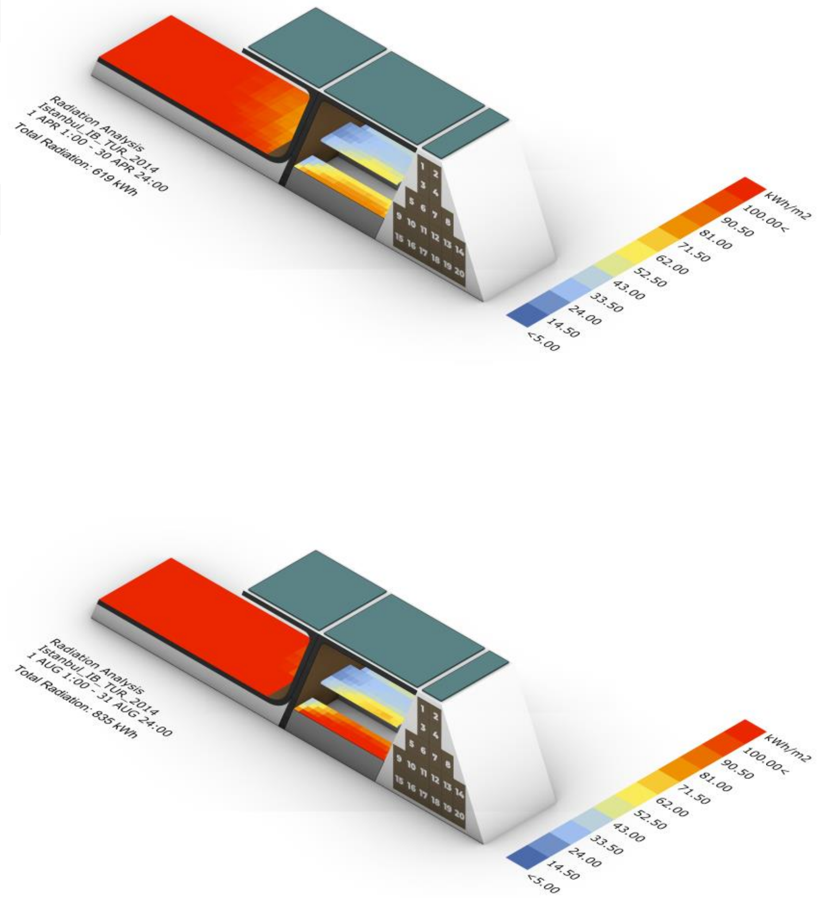


Figure 4.13. Total radiation analysis for April and August of Alternative 3

The sitting module at the side takes a lot of radiation amount as seen below, which could state a discomfort especially in warmer seasons. Since the roof does not fully cover the surface beneath it does not influence the comfort of the users sitting underneath.

4.5.1.6 Total Sunlight Hours Analysis

The sunlight hours analyses are conducted for April and August, in order to be compared with the other alternatives sunlight hours results. As shown in the Figure 4.14 the middle module that works as a table does not take much sunlight with respect to the other modules. The reason for it is the vertical elements that works as sunshades.

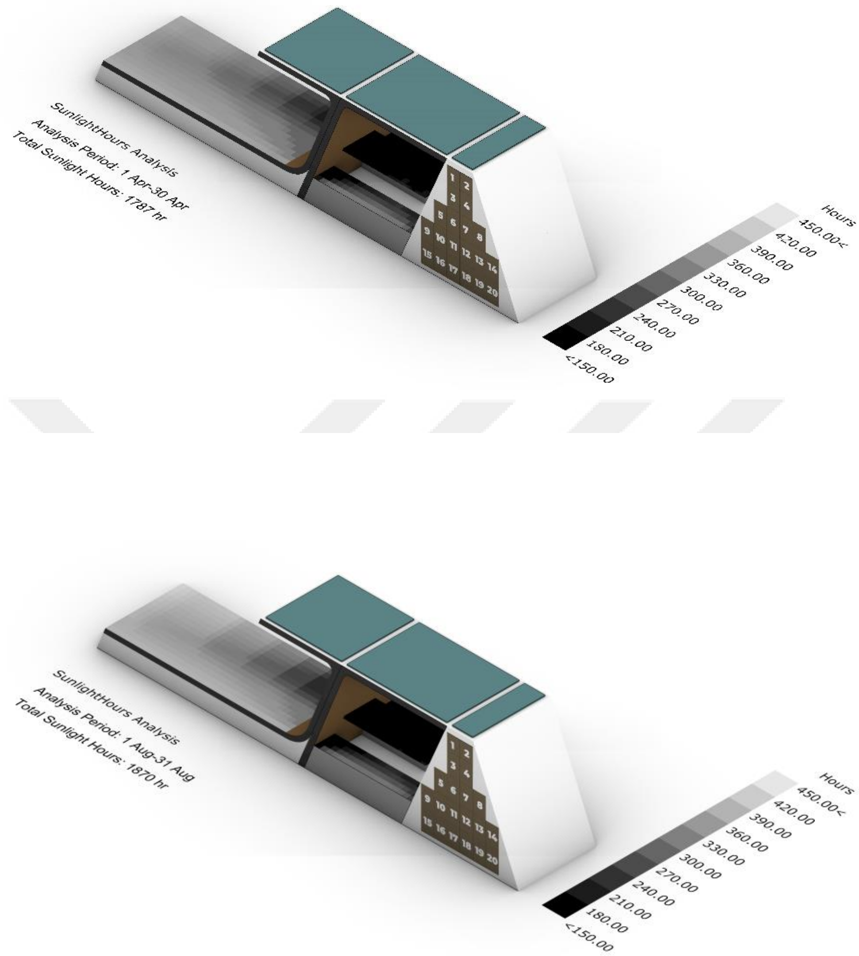


Figure 4.14. Total sunlight hours analysis for April and August of Alternative 3

While the total sunlight hours result in April is 1787 hr, in August this number is 1870 hr. It is understood that there is not much difference in for the sunlight hours analysis between two months. Therefore, it could be stated that the radiation result does not directly relate to the sunlight hours analysis.

4.5.1.7 Solar Adjusted Radiant Temperature

The solar adjusted radiant temperature analysis indicates the radiant temperature that is derived from shortwave solar radiation. As seen in Figure 4.15 below, the shading elements on the left hand side of the figure create a lower radiant temperature, while the right hand side is demonstrated with red colors, as a result of the sunrays coming from the surrounding surfaces.

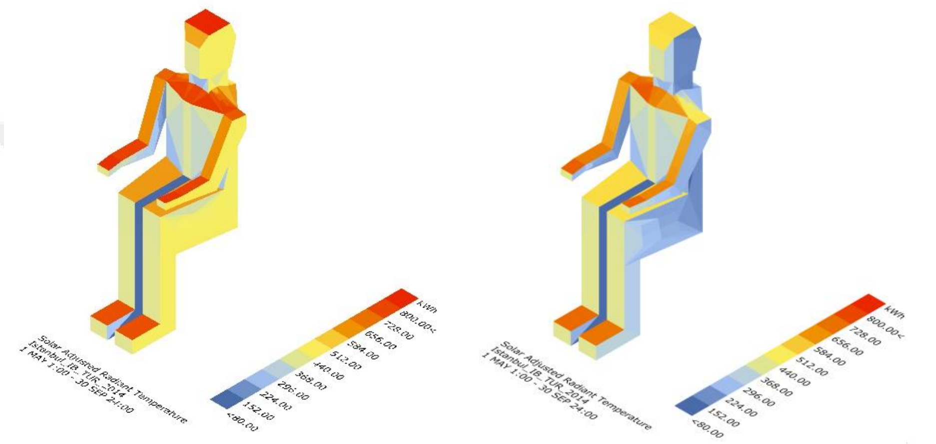


Figure 4.15. SART analysis from May to Septembr of Alternative 3

4.5.1.8 Modularity

The modular system of Alternative 3 resemble to the second alternative. The modules could (as indicated in the previous sections) be used separately. The sitting unit could be connected to the table unit. Unlike the other alternatives, in Alternative 3, the table module is the binder for the other side modules (Figure 4.16).

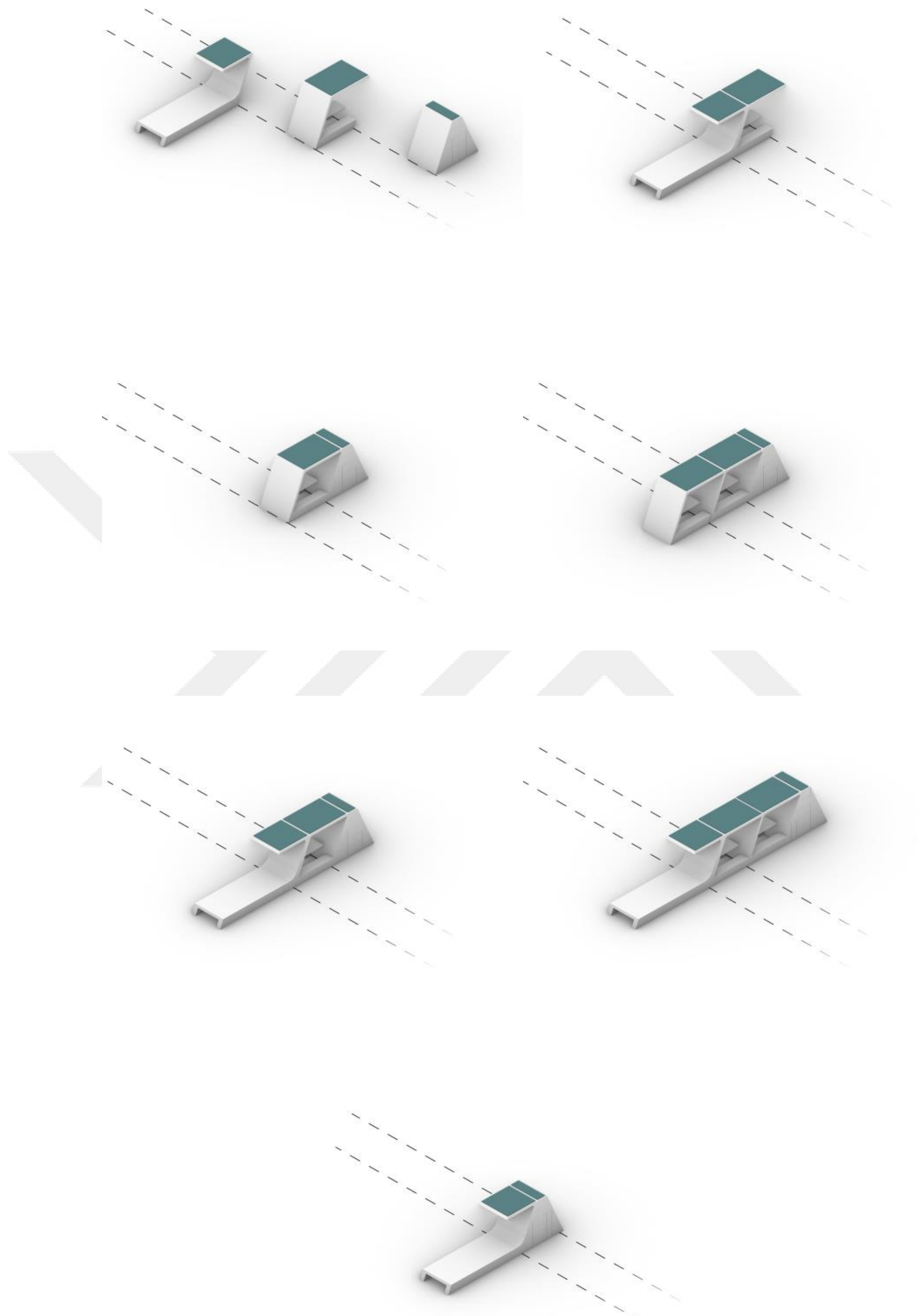


Figure 4.16. Modular variation of Alternative 3

4.5.2 Urban PV Integrated Process of Alternative 3

The area of the PV panel for Alternative 3 is 5.25 m^2. 2.05 m^2 of the module feeds the sitting unit, while 2.7 m^2 generates electricity for table unit, and 0.5 m^2 feeds the storage unit. The flat shaped PV system connects all the modules together. The requirements for the services that the storage unit proposes are; electronic register and e-scooter charger. The services the table and sitting units offer is electric device charging, Wi-Fi hotspots and lightning.

Concentrated PV cells and Thin Film Solar Panel would not be compatible with the needs and formal system of the SUF. As a result, Monocrystalline Solar Panel is a proper type for applying PV integration.

Since there would be a storage unit in order to recharge the batteries of e-scooters, there would be an energy need of 200-500 W.

4.6 Alternative 4

The design principle of this urban furniture is to fold plates into each other in order to reach a structure that defines a space for the services of the smart urban furniture. The most important and advantageous opportunity for such kind of a structural and design alternative is to provide optimum roof tilt in order to get maximum benefit of the sun rays. As seen in the Figure 4.17 the roof, on which PV panel is going to be implemented is not parallel to the ground.

Figure 4.17. Alternative 4

Unlike the other alternatives, this structure is composed of four distinct modules, whose common connection parts are the tilted roof itself. The folding edges provide geometries that people may use for resting, working etc. The folded surfaces may turn into a desk, while creating a sitting area. Resembling to the other explained alternatives the material selection is wood and aluminum composite panel.

4.6.1.1 Safety

Alternative 4 demonstrates a folding structure type, which needs proper installation in order to provide static balance. Coupled with the semi-closed shape the structure proposes, the design creates a space in the middle that is not directly exposed to sunlight. As a result, in order to respond to the safety requirements, the design needs lightning in certain parts (Figure 4.18). The folding surfaces are proper edges in order to implements linear lighting. As a result, in order to state a sense of safety, the lighting is used.

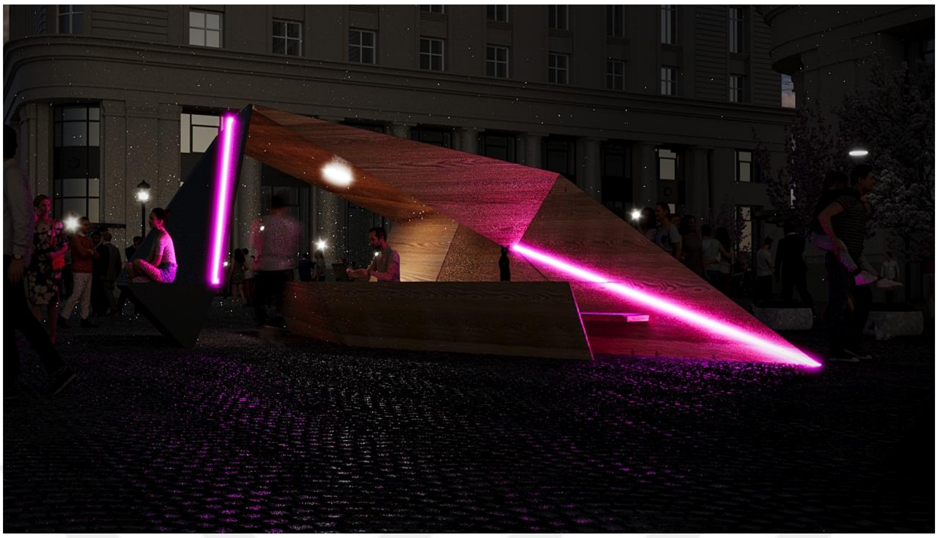


Figure 4.18. Alternative 4 at night

4.6.1.2 Form and Function

The formal arrangement of the 4th alternative is a folding structure whose surfaces continuously transform from the roof to the walls and seating areas. The folded roof becomes a suitable surface in order to receive direct sunlight. According to the measurements that are calculated, the perfect angle to obtain direct sunlight is 22°. The formal organization allows to fold the roof in the perfect angle.

The structure is divided into four main parts which work as table, storage and sitting unit. Moreover, the IT function of the design alternative is to work as storage protected with electronic registers. The electronic device chargers are other functional features of the energy functions.

4.6.1.3 Maintenance

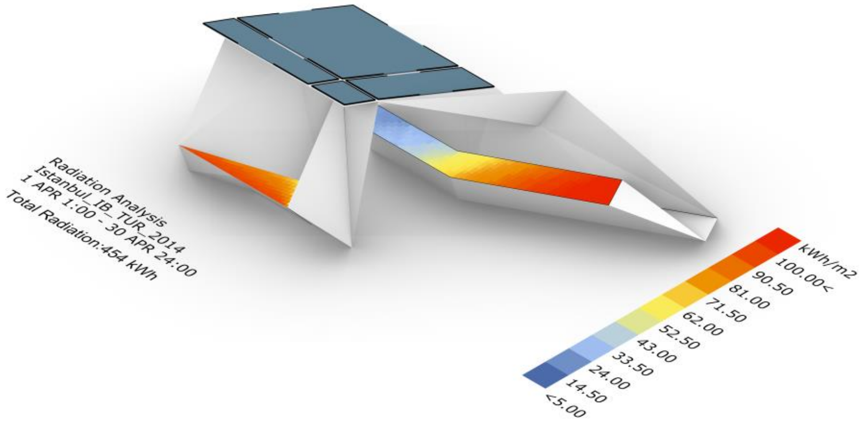
Since convenient maintenance is important in smart urban furniture, the use of metallic material on the outer surfaces enables easy cleaning advantage to the urban furniture. Moreover, it preserves the surfaces from vandalism that is caused from graffiti paintings.

4.6.1.4 Sustainability

Since the structure could be described as semi-closed, it is likely to absorb noise from the environment. In order to refrain from the noise, the inner surfaces are selected as wood material, which works also as acoustic panel because of its sound absorbance. Coupled with the low thermal conductivity, the surfaces become sustainable for their multifunctional features.

4.6.1.5 Total Radiation Analysis

The total radiation analyses are indicated below in Figure 4.19. Alternative 4 differentiates from the other modules, in terms of dimension and the space for walking in between the modules. As a result, this inevitable influences the radiation analyses. In April the radiation amount hitting the surface is 454 kWh, while this number is 664 kWh in August. There are two main reasons why the results are less than the other alternatives radiation results. First, the sitting and table spaces are less than the other alternative modules. The second is the shading effect of the roof above the table module.



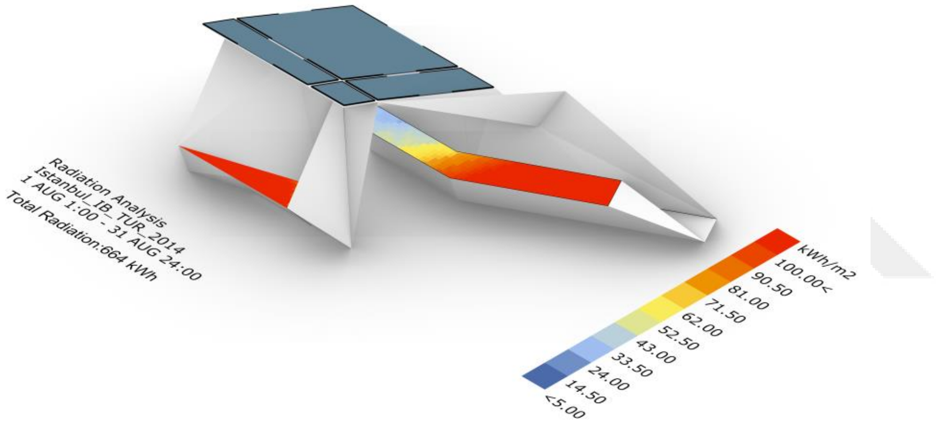


Figure 4.19. Total radiation analysis for April and August of Alternative 4

4.6.1.6 Total Sunlight Hours Analysis

The sunlight hours analyses that are conducted for April and August depict similar results. In April the sunlight hours hitting the surface of the urban furniture is 1893 hr while, in August this number is 1894 hr. As shown in the Figure 4.20 the sitting unit gets more sunlight while the table module gets less because of the shadings on the top of the modules.

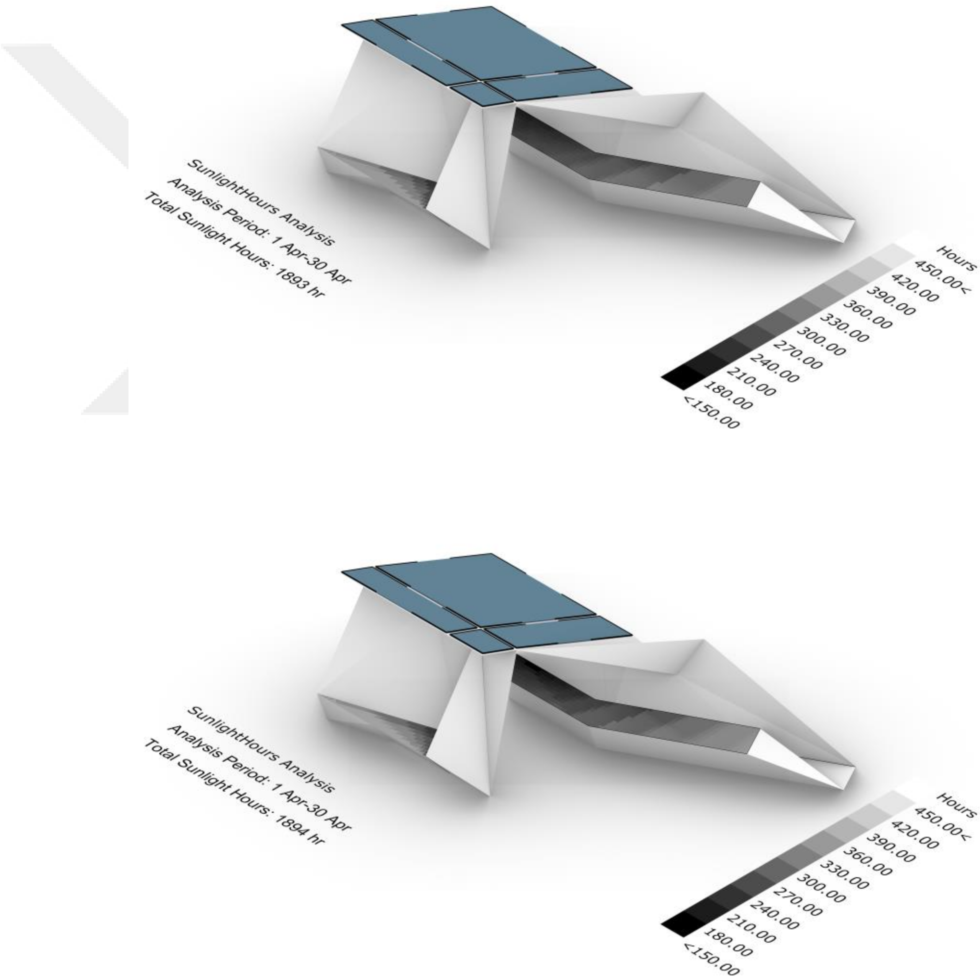


Figure 4.20. Total sunlight hours analysis for April and August of Alternative 4

4.6.1.7 Solar Adjusted Radiant Temperature

The solar adjusted radiant temperature is shown in Figure 4.21 below. The first human figure is placed outside where no shading context exists. The second figure is placed under the urban furniture next to the table. Since Alternative 4 has a larger shading surface which creates a transitional space inside, the radiant temperature that is absorbed from the surrounding surfaces is less than the other alternative designs.

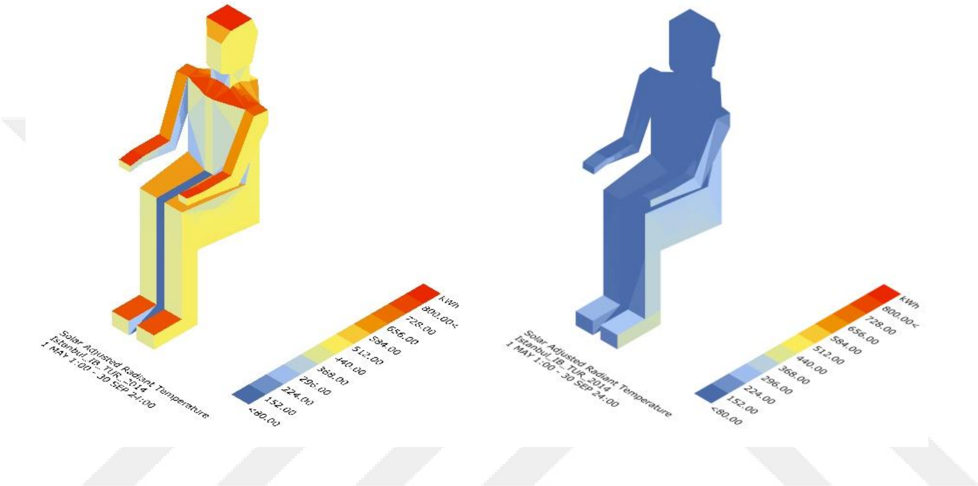


Figure 4.21. SART analysis from May to September of Alternative 4

4.6.1.8 Modularity

The modular system in Alternative 4 is offers less combination variation than the previously explained modular systems. The modular system is composed of 4 main elements (1 sitting, two table, 1 storage module). Since the angular geometry could only be brought together under certain surfaces as indicated in Figure 4.22, it becomes difficult to create several modular combinations. For this reason, the roof structure is formed in order to become the common surface for module connection. The disadvantage for this modular system is that, it could not be enlarged for certain spaces of uses. When all the modules are connected to each other, the modular system encloses itself.

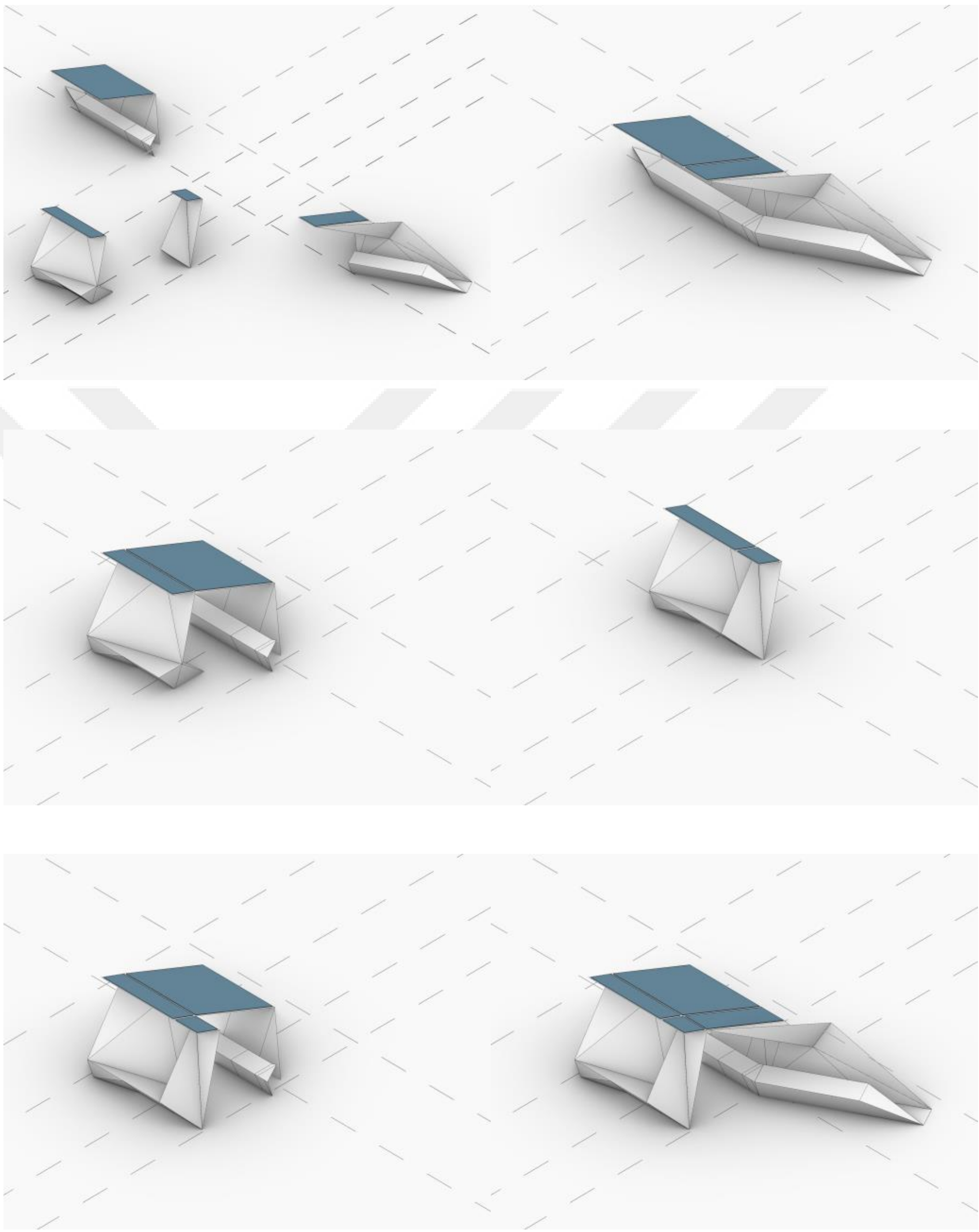


Figure 4.22. Modular variation of Alternative 4

4.6.2 PV Integration of Alternative 4

Photovoltaics could convert solar radiation into electric energy by means of PV panels. Patt et al., (2013) state, “Currently, they can convert up to about 20 % of incoming solar radiation into electricity, with higher values achievable for technologies that first concentrate sunlight”. As shown in the previous sections, this SUF design alternative places the PV panel on a tilted surface in order to get optimum solar energy from the sun. Therefore, unlike flat roof alternatives, this design option is more efficient in terms of solar energy. The area of PV panels is indicated below;

Table Area 1 (m^2)	Table Area 2 (m^2)	Sitting Area (m^2)	Storage Area (m^2)
10	3.09	2.60	0.81

As mentioned in chapter 3, there are certain factors that should be taken into consideration. Firstly, the location that the smart urban furniture is located is prone to hailstorms, which cause destruction for PV panels because they are directly open to it. The weather storms could cause any fractures in the glass panels that are protecting the PV cells as mentioned in the previous sections. Deteriorations could result in, efficiency reduction for the smart urban furniture. “For the international standard qualification test IEC 61215 for crystalline Si, panels must withstand 11 impacts of 25mm hailstones at 23m/s” (Kurtz et al.,2009, as cited in Patt et al., 2013).

Moreover, the temperature is another decision parameter for PV integration. “Increased temperature has a negative effect on current thin-film” (Mohring et al. 2004). As a result, the monocrystalline PV panel could be integrated to Alternative 4, because of the temperature average in the specific location.

4.7 Alternative 5

Alternative 5 is composed of three modules that are connected into each other by side to side. Compared to the other design alternatives, this option is smaller in length. The structure is not semi closed, but has an inclined roof surface to open room for PV panels (Figure 4.23). While creating shading effect for users, the angle also enables the sun rays to hit directly to the panel.

Figure 4.23. Alternative 5

4.7.1.1 Safety

The shading element on the top of the smart urban furniture, creates a partial protection from the rain for the users sitting underneath. The sloped roof is covered with composite material, which is durable against water. The underside of the sitting units are equipped with linear lighting in order to increase the sense of safety in the dark.

4.7.1.2 Form and Function

The functional service that Alternative 5 represents directly coincides with the services that the previous alternatives offer. Sitting unit, table unit and storage unit is the main services and functional parts of the design alternative. The formal arrangement is organized so that the common surfaces of the design becomes the roof structure. So that there would be a compact arrangement of three different services.

Other functions could be classified as energy function which comprises electronic device charger, and e-scooter charger. Moreover, the physical function would be described as protecting, resting, and cooling.

4.7.1.3 Maintenance

In order to increase the applicability of maintenance, the dimensional proportions of the smart urban furniture are arranged accordingly. The sitting units, the table and other elements are standardized for easy maintenance. The surface, as mentioned in the previous sections, are important in case of any graffiti paintings. Therefore, the resistance should be established to tackle with any interventions to the smart urban furniture.

4.7.1.4 Sustainability

The simplicity of the design is important for establishing a sustainable smart urban furniture. The design with use of minimum materials are the key stone for creating this simplicity. Coupled with the standardized service components, the design would serve for a long period of time.

Another important parameter is the heat protection. The inclined roof that absorbs direct sunlight would preserve overheating of the users below. However, the surface proportion is respectively smaller, which results in, a large space directly hit by sun radiation. The further calculation would be presented in the upcoming section.

In order to refrain from the pressure coming from the wind, the triangular void in the middle part of the smart urban furniture is organized, so that the wind would penetrate through the structure and does not put large amount of pressure into it.

4.7.1.5 Total Radiation Analysis

The radiation analysis conducted for Alternative 5 is indicated in Figure 4.24 The amount of space the design covers is less than the rest of the design alternatives. In April the total radiation amount is 310 kWh, while in August this amount is 438 kWh. The total radiation map resembles to alternative 2 and 3 since the roof structure and form is similar to these design alternatives. The sitting space absorbs the most radiation amount compared to the other modules. The roof structure is tilted in order to catch maximum amount of sunrays. However, since the surfaces are smaller compared to the other alternatives the orientation of the urban furniture becomes imperative.

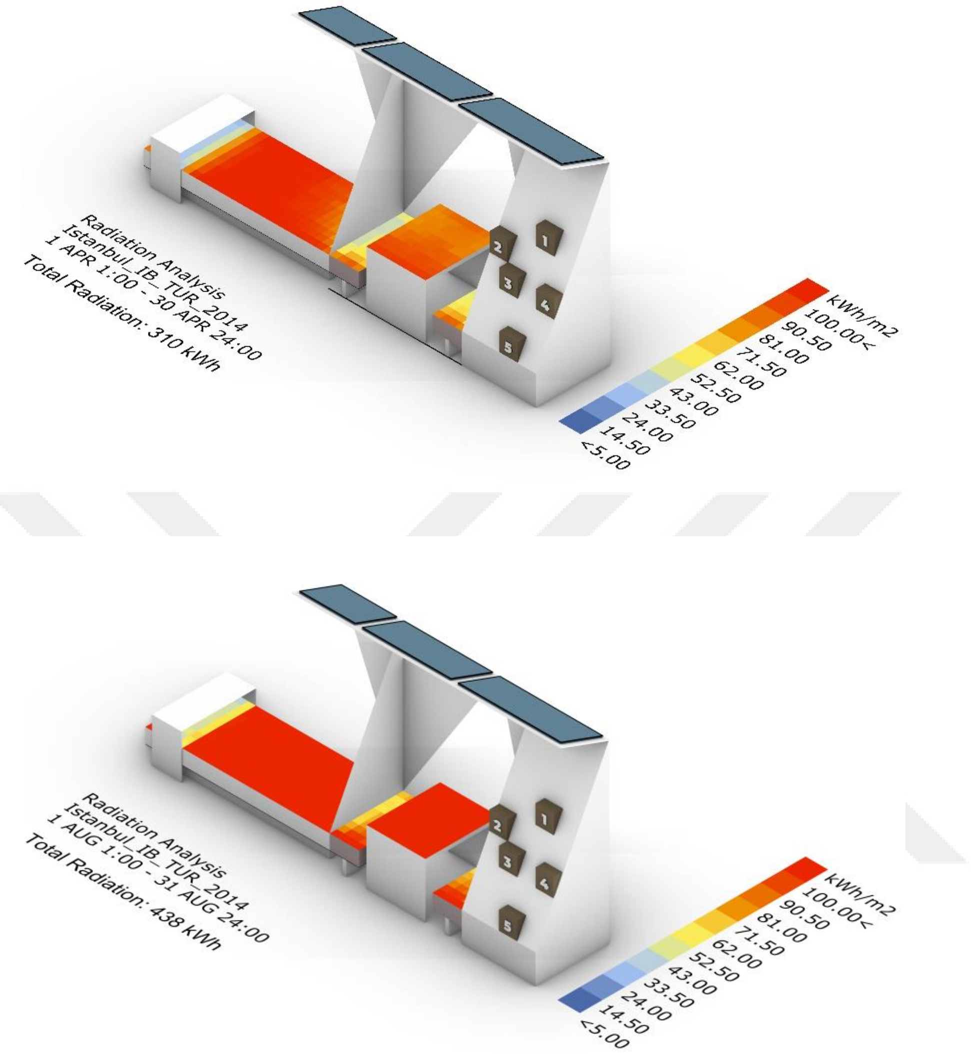


Figure 4.24. Total radiation analysis for April and August of Alternative 5

4.7.1.6 Total Sunlight Hours Analysis

The sunlight hours analyses is demonstrated below. While in April the sunlight hours amount is 997 hr, in August the sunlight hours is 1055 hr. Unlike other design alternatives the roof structure does not respond to the shading needs underneath. This might create discomfort for users.

As seen in Figure 4.25 only the sitting components in the table module takes less sunlight which states a comfort zone in this area.

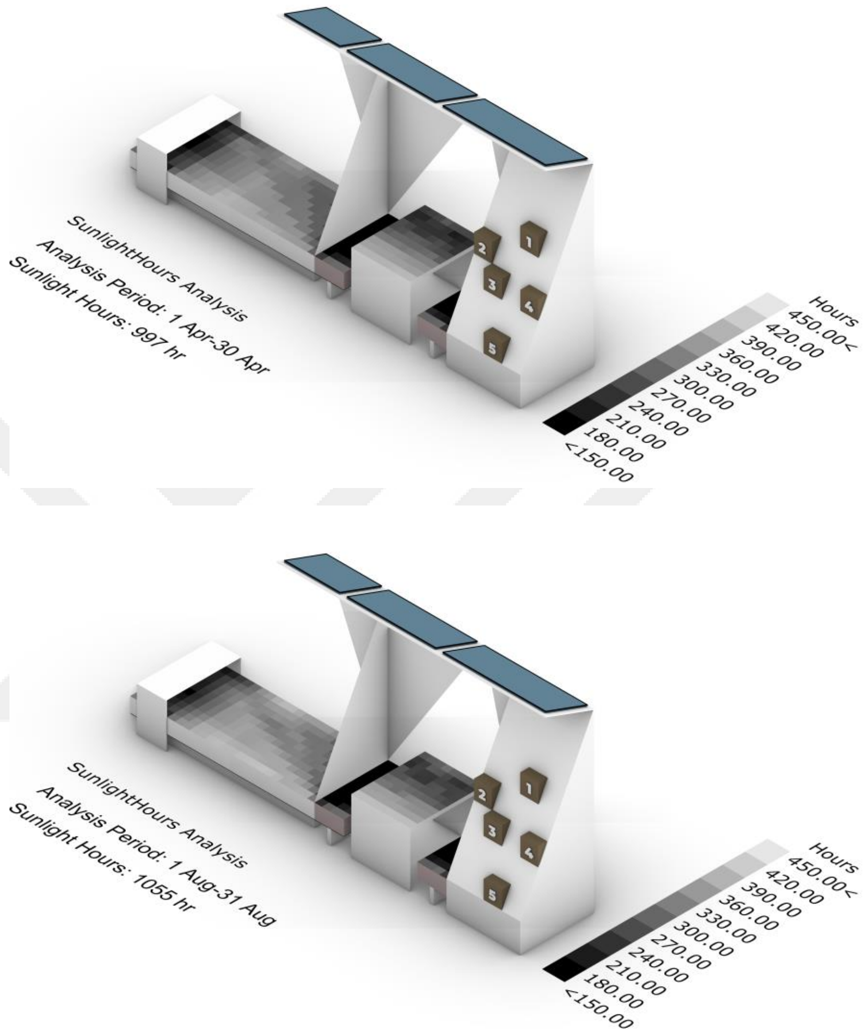


Figure 4.25. Total sunlight hours analysis for April and August of Alternative 5

4.7.1.7 Solar Adjusted Radiant Temperature

The solar adjusted radiant temperature analysis indicates a similar result with the figure that is not covered with any context shading. The figure is placed on the sitting module which is exposed to direct sunlight. Since there are little shading surfaces, the mannequin map is not changed (Figure 4.26).

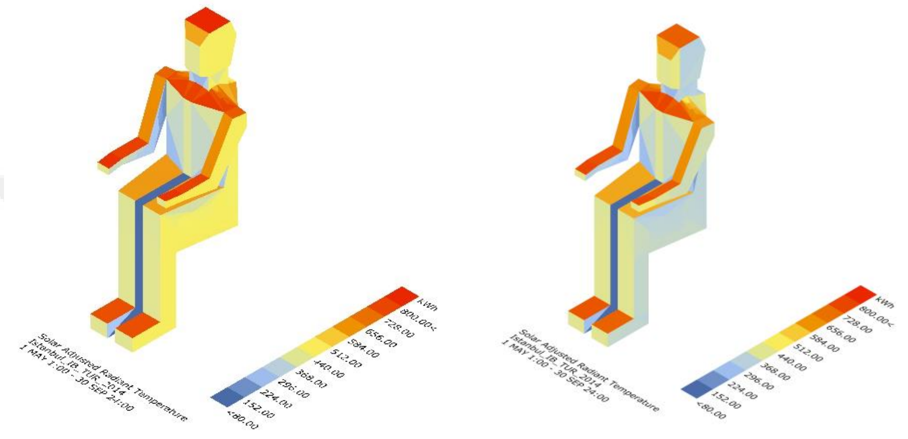


Figure 4.26. SART analysis from May to Septembr of Alternative 5

4.7.1.8 Modularity

Demonstrated in Figure 4.27, three different modules are defined for the urban furniture. These are serving as table, sitting unit, and storage modules. These could be used separately, or could be connected in two or three module connected variations. In this alternative the side surfaces are less likely to be connected into each other. However, the surfaces that are working as the binder are shaped in the same form with each other.

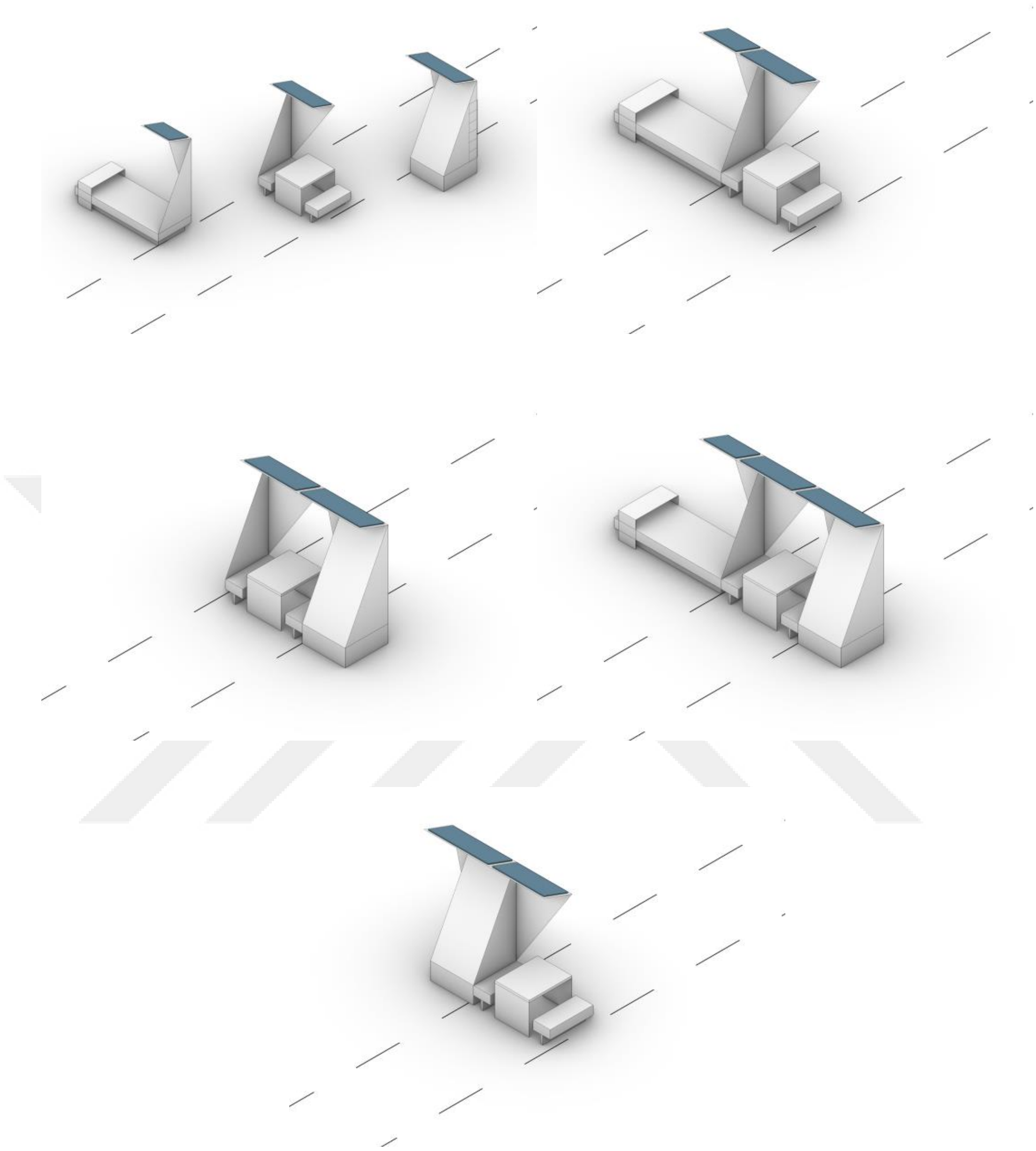


Figure 4.27. Modular variation of Alternative 5

4.7.2 Urban PV Integrated Process of Alternative 5

The area of the PV panels in alternative 5 is indicated below.

Table Area (m^2)	Sitting Area (m^2)	Storage Area (m^2)
0.72	0.50	0.80

Before implementing the PV panel on the top of the roof structure, the decision of the proper PV system is important. As mentioned in the previous design alternative integration process, the PV panel should be resistant against collisions, such as hailstorms, extreme temperatures, and wind. “For the international standard qualification test IEC 61215 for crystalline Si, panels must withstand 11 impacts of 25mm hailstones at 23m/s” (Kurtz et al.,2009, as cited in Patt et al., 2013).

The second concern is the temperature. High temperatures reduces the efficiency of the PV panel. As a result, in context which the temperatures are high annually, should be analyzed accordingly. Therefore, thin film PV panels should not be integrated since their resistance against extreme heat are comparatively low.

4.8 Alternative 6

The main body is a 12m long linear shaped geometry. The Figure 4.28 below shows the stages that end up with the final result. At the first stage two plant beds are placed in the middle and head side of the structure, whereas the tip is served for parking spots. Since the geometry is intended to be modular and connected in distinct variations, the head of the structure was formed in order to be connected with the middle part of the body. As seen in Figure 4.28 below, three main modules in which two of them are used for resting and cooling purposes whereas the last module as used the tip of the body is used for cycle parking plot.

Figure 4.28. Alternative 6

At the end of the phase the first part has a 5m length while the middle part is 3m and the tip of the body is 4m long. As a result, the main body becomes a linear, modular shaped geometry which becomes the base structure for the PV panel roof that would be implemented on the top. There are sitting units, plant beds and parking spots in the main body. Furthermore, there is also a room for battery storage.

4.8.1.1 Safety

There are two important issues that the safety metric is directly affected. Firstly, the roof height is important for human safety since it would bother the users or cause any accidents. Therefore, the sides of the curved roofs are arranged so that any discomfort for human posture would not expected.

The second safety parameter is the material selection of the surface in which people would sit on. While the thermal conductivity of a material is high, it is prone to convey directly the energy it emits to the other source. The equation of Thermal Conductivity is;

$$q = -k.\nabla T$$

While the q is the heat flux, k is the thermal conductivity and the ∇T is the temperature gradient.

On order to protect people from direct heat transfer in cold and hot weather conditions, there has to be a low thermal conductivity material. Therefore, in the urban furniture sitting surfaces wood material is used since it has a thermal conductivity of 0.1 – 0.2 W/mK.

Another important factor is the vegetation element. There is planted two plants in order to provide aesthetic quality as well as working as a cooling element. An important factor while planting vegetation, evergreen plants should not be used, because of their physical form and sharp leaves.

4.8.1.2 Form and Function

The form of Alternative 6 is a linear seating body that is supported with steel columns. The formal arrangement of Alternative 6 is composed of three main modules, two of which work as seating while the last part is used as e-bike parking plot. The PV panels are working as protection elements for the vegetation that are planted below.

The IT function of alternative 6 is to serve as a Wi-Fi hotspot, while the energy function comprises electronic device charger and e-bike charger as main services. The physical function of the smart urban furniture is protection from sunlight, resting area, and parking.

4.8.1.3 Maintenance

While designing the smart urban furniture, a significant criterion is the maintenance of the structure. After the placement of the furniture, the design will be prone to vandalism, which is an imperative reason for feasible maintenance implementations. In order to provide easy maintenance conditions, the PV panel pieces state a great significance. As a result, in the PV integration process the parameter maintenance would directly affect the design operations.

4.8.1.4 Sustainability

Heat is an important parameter that directly affect the sustainability of the smart urban furniture. As a result, the heat should not be directly transmitted to the user. The steel supports that are carrying the PV panels are surfaces that the users are likely to touch. Therefore, there ought to be implemented low heat transmittance materials. The PV panel should also state a shading effect to the users and vegetation underneath.

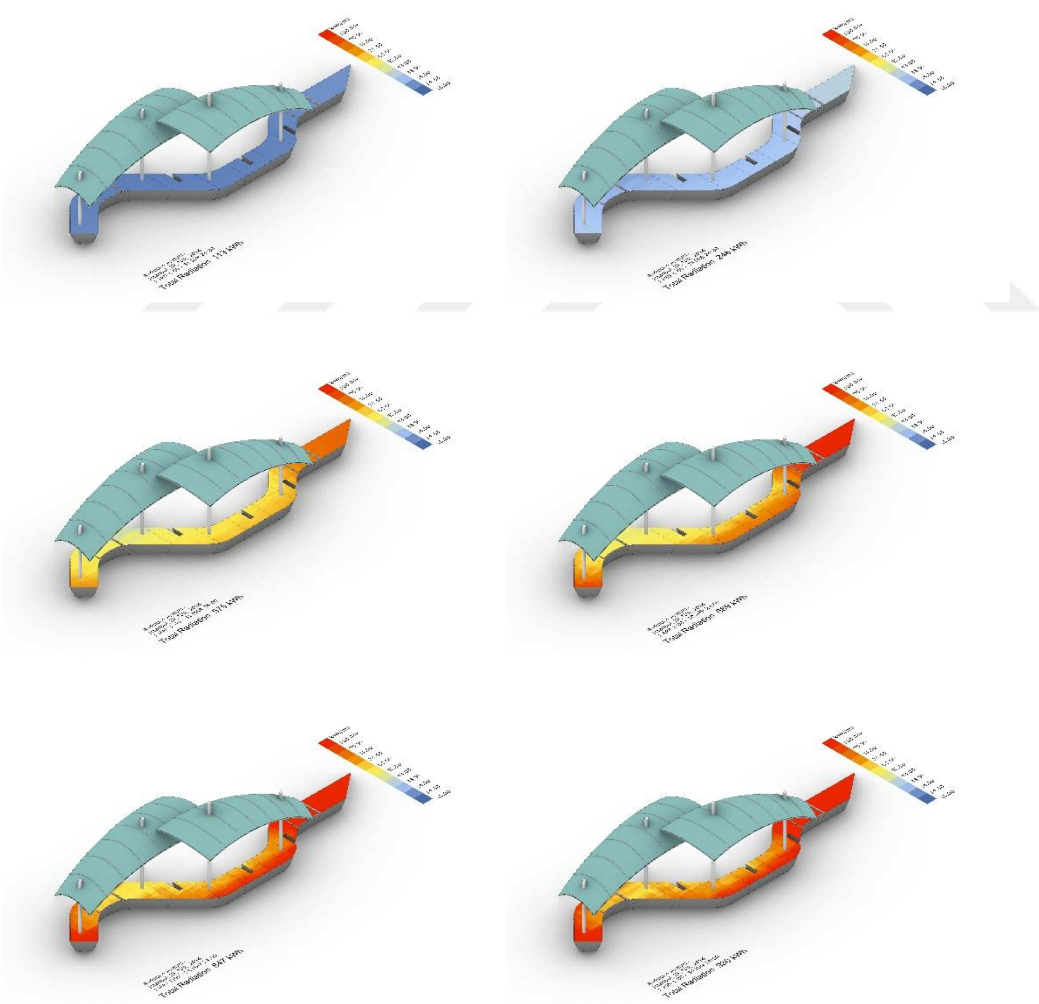
The rain is another parameter that is directly related with sustainability of the smart urban furniture. The discharge of rainwater from the furniture and roofs is important, since it would have a decaying effect on the materials of the SUF. The structure should also resist to the wind pressure that the specific location would influence. As mentioned in the previous sections the wind speed in Istanbul reaches 9 m/s coming from the northeast and southwest.

4.8.1.5 Total Radiation Analysis

While placing the PV panels on the top of the main body the form is shaped in order to maximize energy efficiency and not to interrupt the production of energy of each module. However, the PV panels are also placed in order to provide maximum thermal comfort to the users that would sit under the PV panel roof. In order to count and calculate the radiation the model is created in Rhinoceros, and the total radiation is analyzed in the Ladybug tool (a plug-in in the grashopper interface).

While controling the results, analyses carried out in daily basises might include time periods which may mislead the synthesis stage. As a result, the analyses were done in monthly periods which includes all the days of the year. This would prevent some misleading results coming from the extreme hot and cold days of a month.

The Figure 4.29 below shows the monthly total radiation analysis. It could be easily comprehent that the tip module of the overall urban furniture emits higher radiation in a year.



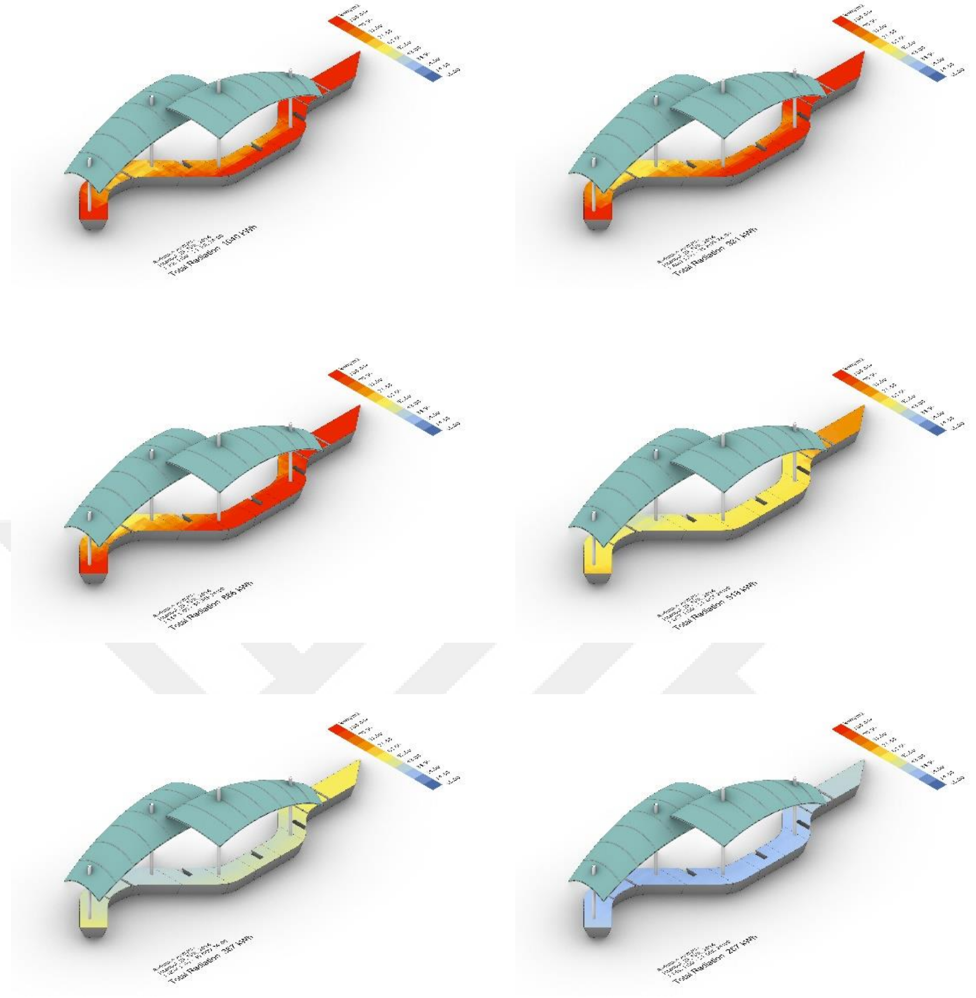


Figure 4.29. Total radiation analysis for Alternative 6

The reason for emitting higher radiation than the other two modules is that the last module is not sheltered with a roof which causes direct sunlight to hit the surface. The highest radiation amount hits in July with 1040 KWh. The lowest radiation amount is in January with 113KWh. Although the PV panel roof provides a sheltering effect to the users below, the sun might state discomfort in the extreme hot conditions in summer weeks. Moreover, the curved and bent shape on both directions of the PV panel structure prevents the sunlight from hitting the main body surface more than the straight shaped geometry. Although it has slightly a minor impact on the radiation energy, coupled with the aesthetic feature it describes, it becomes an important parameter that would shape the overall design.

Based on the total radiation analyses that are conducted with the first version of Alternative 6, the roof width is decreased in order to tackle with the wind pressure. As a result of this formal arrangement, the total radiation analysis is conducted for the revised version (Figure 4.30). Not only, the roof dimension, but also the e-bike plots are shifted to the tip part of the structure. The radiation results for April and July are recalculated as seen in Figure 4.30 and the results are indicated as below.

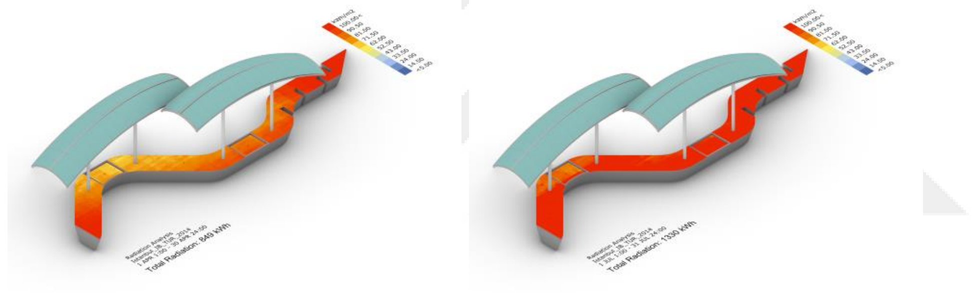


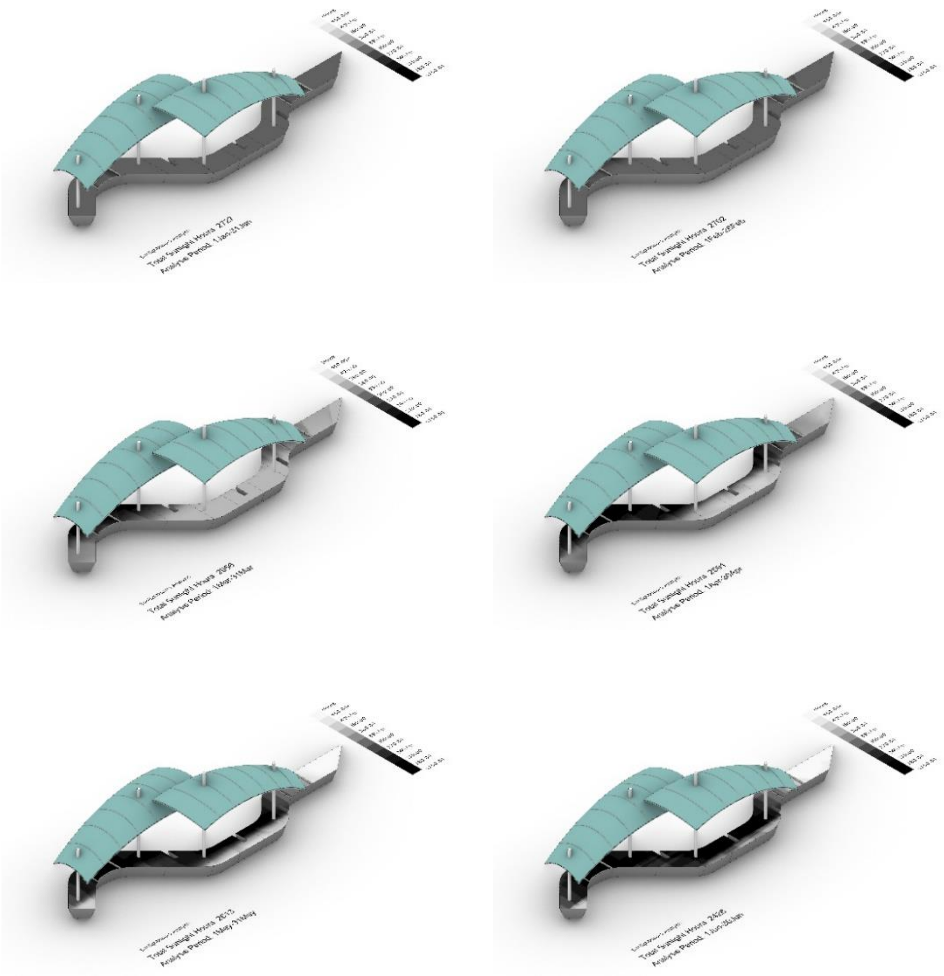
Figure 4.30. Total radiation analysis for April and July of Alternative 6

The radiation results in April is 849 kWh, while this number is 1330 kWh in July. Compared to the first version of alternative 6, the surfaces are exposed more to radiation. This might result in a discomfort in warmer periods. However, based on the flowchart that is explained in Chapter 3, the safety parameter which comprises also the stability sub-factor and the sustainability parameter which includes the wind sub-factor has direct influence on the constitutive organization of the design development stage. As a result, although total radiation is higher in this revision, since the safety and sustainability parameter is the primary decision factor in the flowchart the new version of alternative 6 would become compatible with the objectives.

4.8.1.6 Sunlight Hours Analysis

The sunlight hours analysis helps to comprehend the sunlight that hits a specific surface and revise the design according to the data that is conveyed. It mostly draws a corresponding graphic with the Total Radiation Analysis. As shown in the Figure 4.31 it could be understood that while the southern part of the structure takes more sunlight, the northern part of the main body has the advantage of the orientation.

In the sunlight hour analysis, unlike the Total Radiation Analysis where July receives the most radiation, October is the month that receives the most sunlight with 3027 hours on an hourly basis. June receives least sunlight hours with 2428 hours on hourly basis.



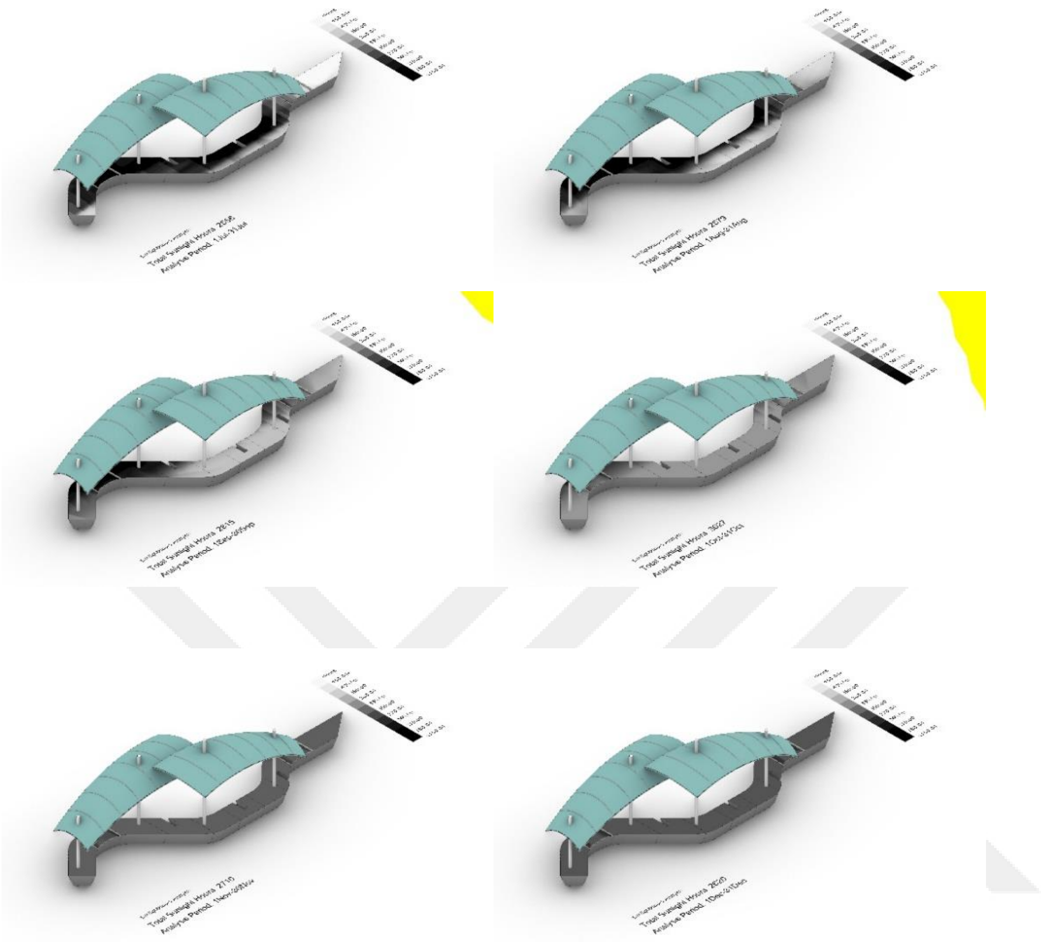


Figure 4.31. Total sunlight hours analysis for April and August of Alternative 6

As a result of the analyses that are done in monthly basis it could be easily comprehend that in winter season the sun hits from a narrow angle, while it hits the surface from a perpendicular angle in hotter season. In order to refrain from the discomfort of direct sunlight the PV panel roof structure is extended in both sides. The reason for extending it in both sides is to provide freedom in terms of placement in various directions. The extended structure creates a cantilever and shading effect on the bottom.

Since the parking plot on the tip part of the design has less space for resting or sitting, the sunlight hitting the surface constitutes not a burden for the comfort of the users. Therefore, there is not applied any shading element on the tip part.

From the analyses it would be understood that the first module takes the least sunlight on hourly basis. The reason for this is the PV roof that is placed on the second module, which creates a shading effect by prohibiting sunlight from the south direction. If the overall urban furniture would be placed on the opposite direction the reverse condition would be valid. The second module would take the least sunlight on hourly basis.

All in all, the sunlight hours analysis has directly affected the design stage. The orientation of the roof structure has been arranged according to this analysis.

4.8.1.7 Solar Adjusted Radiant Temperature

After implementation of the PV panel roof the solar adjusted radiant temperature could be observed in Figure 4.32 below. In the first count, the human body is placed on a space with no shading elements above, while the second analyses show the result, in which the PV panel roof is above the figure. It could easily be comprehended that the roof acts as a shelter to protect from direct sunlight in months with a high average temperature. The analysis period is from May to September. As seen in Figure 4.32 the human body shows the solar adjusted radiant temperature. This analysis type is used in human comfort indications.

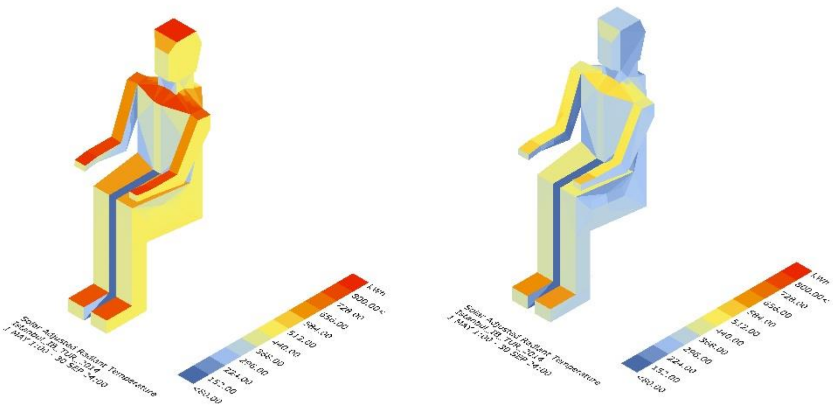


Figure 4.32. SART analysis from May to Septembr of Alternative 6

4.8.1.8 The Structure of the Smart Urban Furniture

After the analyses that are carried out taking into consideration the total radiation, sunlight hours analyses, material selection, and modularity the structuring process has been started. There are three main parameters for the structuring process;

- Applicability
- Maintenance
- Comfort

The urban furniture could be placed on a crowded plot. Therefore, it is likely to be prone to vandalism, which will be a main problem statement in the structuring phase.

4.8.1.9 Applicability

The main structure is made of concrete by using the 3D printing technology. The detailed explanation of this type of fabrication is mentioned in the previous sections. The reason for choosing this fabrication method is saving from the time. In order to support the main body, steel supports are used. The steel supports are also carrying the PV panel roof. Since the PV panel roof could not be connected directly to the main body, by taking into consideration also the transferability of the structure, the steel supports were nailed into the main body.

The PV panel roof consist of 10 equally cut PV panels. The reason for this is to require only one type of PV panel geometry from the supplier firm. In order to provide the curved form on the PV paneled roof, the PV panels are bent in both directions, which states a challenge for the fabrication stage.

As demonstrated in the Figure 4.33 the drawing shows the plan view of the glass panels of the roof. As the curved form is intended to be shaped, each glass element is bent in each direction. The middle axis divides the roof into two equal pieces, which also works as the skeleton of the roof structure. Since the pieces are equally cut, refraining from mirroring creates a distinct distance in between the glass elements.

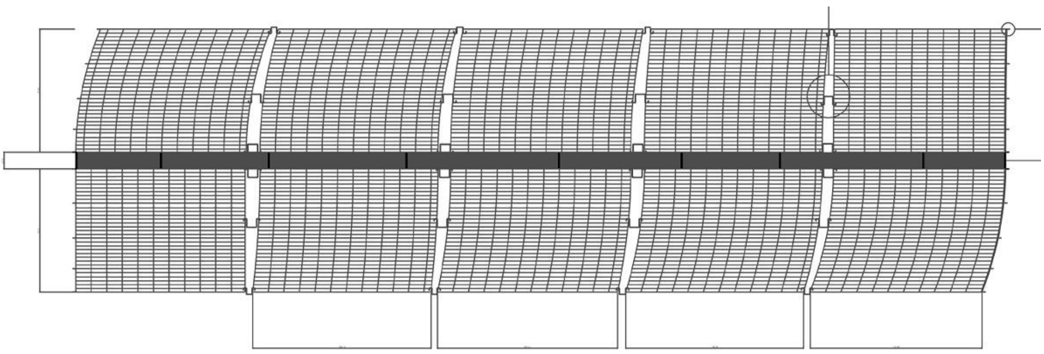


Figure 4.33. PV glass panel plan drawing

4.8.1.10 The Modular Unit Separation

As mentioned in the previous sections, providing distinct variations are important for this project. The reason for this is to increase the adaptability of the design in certain sites. In this project there are three main reasons for the use of modular units;

- To be arranged in various lengths.
- To be suited for certain aims.
- To provide several design alternatives for aesthetical concern

The length or the use of the design could be arranged accordingly. Mentioned above, the design is composed of three unique modules which could be connected together in different ways. The Figure 4.34 indicates distinct variations for these modules. The parts which are connected into each other create a linear pattern which could be arranged as much as needed.

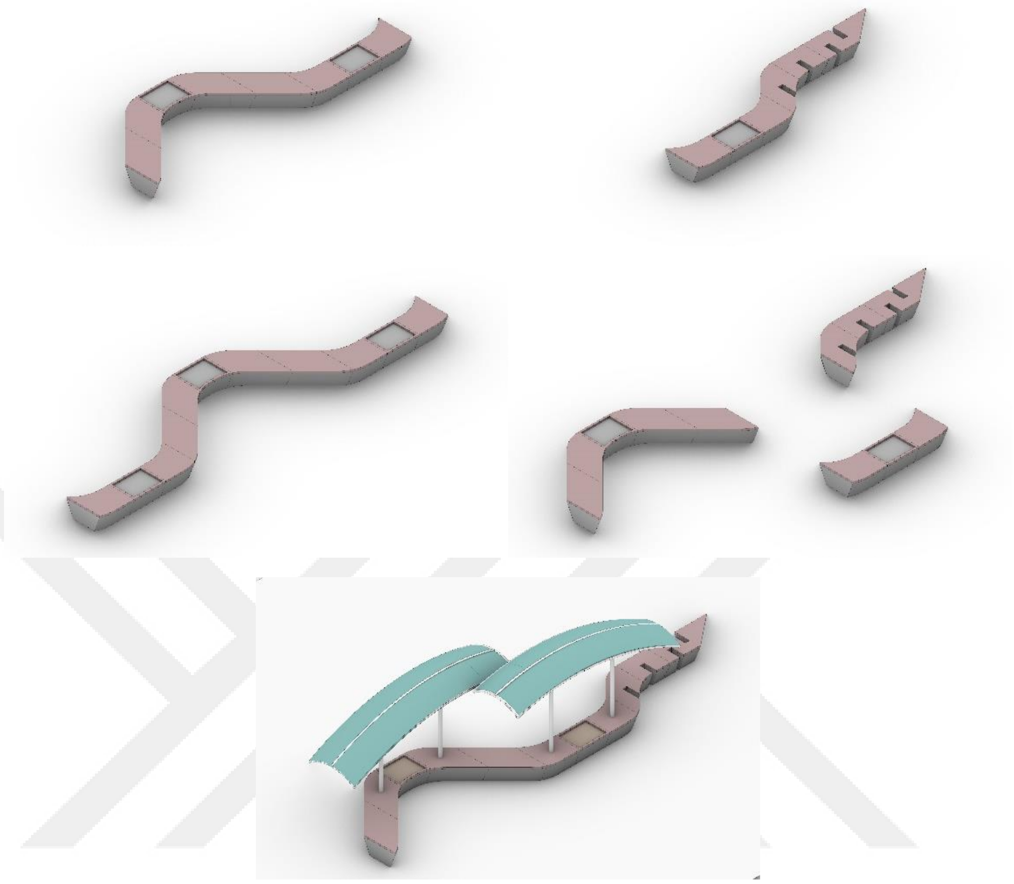


Figure 4.34. Modular variation of Alternative 6

The Figure 4.34 above shows some of the combination alternatives that could be used in a certain site. While all of the modules could be used separately as unique elements, two, three or more modules may also be connected to each other. Some of the combinations are used only for resting services, while the tip part of the design could be attached in order to be used for parking spots for bicycles. Since there are only PV panels in the sitting units, in order to charge the electric bicycles one of the modules should be attached to the parking module to provide energy.

4.8.2 Urban PV Integrated Process of Alternative 6

It is important to place PV panels accordingly in order to ensure maximum energy efficiency. The tilt, the direction that the panels are oriented and many other parameters influence directly the energy efficiency. The aesthetic quality of the PV panel is also mentioned in the previous sections. Therefore, the aesthetic is also taken into account in the PV panel placement and design.

The conventional PV paneling technology does not allow complex geometries, and provides not free space for design. Especially, curvilinear PV panels cannot be implemented with conventional panels. Also the weight of the PV panel is comparatively high with respect to VIPVs.

The PV panel that would be placed on the top pf the main body is decided to be designed curvilinear in order to be adapted in several directions and locations. Certain tilt angles are important to acquire maximum energy efficiency, but the adaptability to any directions and location is another important question problem in this phase. As a result, the curvilinear shape is decided as the PV panel structure. The VIPV (Vehicle Integrated Photovoltaics) is implemented on the curvilinear structure that would be the bed, on which the PV panels could be implemented.

The PV beds are made of glass, which would be in 20 equal pieces that are connected together with a steel upper structure. Since the design is a prototype for further research questions the cost becomes a significant question. In order to minimize the cost, the glass pieces were cut in equal dimensions. The number of the pieces also enables to give the curve that would be needed in order to realize the intended geometry.

The area of the PV panel for Alternative 1 is 17.40 m². As mentioned in the previous sections, there are three main modules, which are fed by two PV panel roofs. These PV roofs are identical, being 8.70 m² each. Compared to other alternatives, this design option has more allocated space for PV panels. The structure is a curvilinear roof composed of 10 equal glass pieces. Therefore, considering the aesthetic concern, it is important to choose the PV panel system compatible with curvilinear forms. Thin Film Amorphous Silicon Solar Panels would be the only choice for giving that form.

4.9 Results and Discussion

There are several factors that affect the design stage of an Urban Furniture, such as radiation amount, sunlight hours, comfort level for human body, shading, maintenance, implementation, duration, modularity, integration, service, aesthetics, and many other parameters.

In this regard, the aim of the thesis is to comprehend and research Smart Urban Furniture (SUF) design stages, and use energy simulation tools in order to assess the influence for energy simulated smart urban furniture. Whereas there is a lot of interest on smart urban furniture design, it is understood that there has been done less analysis and simulation based research for the SUF design.

As a starting point, "what are the main drivers for designing a smart urban furniture?" is the essential question that is searched in the thesis study. There are 6 main case studies that are searched and designed taken into consideration the parameters that are mentioned in Chapter 3.

The study investigated 6 different smart urban furniture design alternatives in terms of radiation analysis, sunlight hours, solar adjusted radiant temperature, modularity, and PV integration.

The first case study as named Alternative 1, has three different modules which work separately from each other. When the modules are brought together a semi closed roof envelope surrounds the SUF. While this creates a sense of togetherness in the geometrical form, the continuous roof surface provides a sheltering effect underneath. The radiation analyses that is conducted for April and August indicates that, the roof envelope prohibits the sunrays to hit the sitting surfaces, which creates a cooling effect for the users. The position of the sun directly influences the radiation map since the surfaces looking to the south takes more radiation than the north side.

It is understood from the sunlight hours analysis that there is no direct relation between total radiation analysis and sunlight hours analysis. While the sunlight hours in April are 1838, this number is 1818 in August. Although August is a hotter month, the sunlight hours analysis draws a contradiction with the radiation map. For Alternative 1, the modular combination creates an eternal form when the middle part is used as a binder. However, the side modules work as the finishing components. Therefore, the structure could only be suited for only some extend in different contexts.

The second alternative is composed of three modules similar to the first alternative. The side module which works as a table has also a secondary table unit outside the surface. Although the roof is approximately having equal area with the first alternative, it draws a different picture than the first case. The roof is not completely closed which leads the sitting surfaces to be prone to excessive radiation.

In the radiation map for Alternative 2, the sitting units looking to the south has the same color. It is understood that especially in summer months side shades do not have an important influence on the radiation results. The location of the sun which hits on direct angle in summer weeks accentuates the significance of horizontal shading. In fall, the vertical shadings have a more direct influence on the radiation on the sitting units.

The solar adjusted radiant temperature on the other hand, depicts a different map in summer months. The side of the figure which is close to a vertical shading is exposed to less radiant temperature which constitutes a cooling effect to the users. It could be stated that solar adjusted temperature states a different graph than the radiation map because of the horizontal infrared radiation.

The third alternative is the curvilinear form of the second alternative and resembles in shape. The tilted vertical surface creates a disadvantage in terms of radiation results. The sun hits the sitting surfaces in a direct manner which disables the shading effect of the roof. Although the third case study absorbs more radiation than the second alternative, the solar adjusted radiant temperature analysis results are nearly the same. It accentuates the influence of the horizontal infrared radiation on the users.

The modular system places the table unit on the middle. The surfaces that encloses the table unit could be defined as the binder. Since the side units are not compatible for sufficient number of combination variation this alternative could not be described as modular as intended.

Case 4, is composed of 4 modules whose common surfaces are the roof structure on the top of the modules. Two modules are tables in which users could work, and one module for storage area and other module for sitting space. The radiation analysis that is conducted shows that this alternative takes less radiation in terms of kWh/m^2 since it not linear, in contrast it has a modeling system which creates nearly a closed space inside, which inevitably reduces the total radiation amount hitting the surfaces that people sit on.

The solar adjusted radiant temperature indicates that the spatial shading system creates a cooling effect to the user underneath. The solar radiation analysis indicates that in April the solar radiation amount hitting the surfaces is 454 kWh, whereas in August this number is 664 kWh. Although this result could be considered as logical, regarding the seasonal conditions, the surfaces under the spatial shade could be regarded as equal, while the side modules become more prone to radiation.

Alternative 5 is composed of three different modules which are brought together in a linear connection manner. In order to take sunlight in a perpendicular angle the roof is tilted. However, this create also an obstacle, while the urban furniture is placed in the opposite side this create a burden for getting sunlight. Another result that is understood from the total radiation analysis is that, the roof which is comparatively smaller in size does not state a comfortable space underneath for the users, since the side of the modules are slightly open with respect to the other case studies this accentuates the solar radiation amount hitting the surface.

The 6th Alternative differentiates itself from the other urban furniture cases. The design is defined by three modules which work as sitting and parking plots. The modular design enables an eternal pattern which provides a flexible design option. The first and middle part could be connected so that the urban furniture creates a linear repetition.

The total radiation analysis indicates that unlike the other alternatives the roof is shaped in a curvilinear form, and formed a shell like structure. As a result of the analyses, the shorter roof enables less radiation to hit the sitting surface than the taller roof. The reason for this is that it cuts the sunrays coming from a narrower angle. As a result, the radiation amount is lower under the shorter roof.

Because the aesthetic quality is pursued, the roof structure and the lower sitting units state a contrasting approach. However, this leads some of the areas on the sitting units to be exposed to direct sunlight. That is, this might create a discomfort for the users.

As a result of the studies, it is understood that the shape and the size of the roof directly influence the total radiation results, that hit the sitting surfaces. While absorbing direct radiation, the PV panels provide a shading effect to the surface below. Another important result is the change of the total radiation rate in a yearly period. As mentioned in Chapter 3, total radiation rate changes according to the position of the sun. The maximum total radiation rate is observed in July with 1040 kWh while the minimum rate is 113 kWh in January.

While the total radiation results coincide with the temperature in monthly period, the sunlight hours analyses that are investigating the sitting surfaces represents a different graph. Most sunlight hours are expected in October with 3027, while the second greatest rate is expected in March with 2956 hours.

CHAPTER 5

CONCLUSION

From the very first stage until the final result, all the researches are conducted regarding the concerns of the objectives of the smart urban furniture. Urban furniture is used for several years in cities, they are creative tools in order to provide a living space in the open environment. The lack of consciousness of simulation and analyses based urban furniture design, has led to search on the driving parameters for smart urban furniture. The aesthetic concern while designing urban furniture could be considered as a deficiency in the market and literature.

The recent climatic concerns have opened up a new phase for urban furniture as well. Zero carbon emission aims forced urban furniture to become smarter and climate adaptive. In this sense the thesis study addresses to seek a design method for smart urban furniture concerning the adaptive climate conditions. The modularity and the climate analyses are less used in the fabrication and design phase. Therefore, these two factors are defined as the main question marks in this process. This thesis included these factors and coupled them with the concerns for responding the needs of smart urban furniture services.

The design method is decided according to the lacking factors during fabrication phase in the literature. As well as the design method, the case studies are designed by taking into account the calculation of these parameters that are mentioned above. The roof structure and form, roof orientation, closure, geometry, purpose of use could be described as the main role makers during the case study investigation.

In this thesis study, the objectives that are intended is to establish a new order while designing a smart urban furniture, which takes into consideration several factors. The case studies in this manner state this importance of creating a new design order. The thesis entitles the significance of safety, maintenance, site specificity, sustainability, and form & function parameters. These factors are considered as primary objectives while designing a smart urban furniture. The secondary criteria are represented as; solar adjusted radiant temperature, total radiation, sunlight hours analysis, and modularity. While designing smart urban furniture, a hierarchical flowchart could not be pursued in the practice. This causes to underestimate some of the critical parameters and stages in this process. As a result, a new proposition is suggested for contradicting parameter sets by using a new flowchart (Figure 3.2). The relationship between primary and secondary parameter sets are discussed in the case studies.

The case studies are critical in terms of indicating the design methodology. In alternative 6, the total radiation analysis and wind pressure contradicts with each other. Based on the proposed design methodology, the wind pressure directly affects the safety precautions which are described within the primary parameter concern. Although the total radiation analysis state a high value which could state a discomfort for the users, the alternative 6 is adapted to the safety criterion. The given result indicates an example of the working principle of the design methodology for smart urban furniture design.

The contribution of this study is to provide architects and designers a guide while designing a smart urban furniture structure. The developed design method for smart urban furniture allows architects to make decisions towards a sustainable public spaces in cities. This design methodology creates an organization of decision making processes by taking into consideration total radiation, sunlight hours, solar adjusted radiant temperature, modularity, sustainability, maintenance, form & function and safety analyses.

This design methodology offers a combination of data based analyses and functional approach. This methodology could allow not only integration of smart urban furniture, but also it can be described as a tool that would be used in urban studies and interventions to public spaces.

The goal of the study is to comprehend the current relationship between the formal and analysis based design. The aim is to represent a new design method for smart urban furniture, regarding the design methodology that is mentioned.

The comfort conditions and radiation calculations are conducted to evaluate the performance of the smart urban furniture. As a result of the study, the essential component that should be concentrated on is the total radiation analysis. It is understood that sunlight hours analysis does not coincide with the radiation analysis results. Therefore, the sunlight hours could not be related directly to the performance of the smart urban furniture.

The PV integration is directly related with the aesthetical concerns of the design and the efficiency ratio for the services to provide. Therefore, there is a lot of freedom to choose the right PV system for the urban furniture.

5.1 Limitations of the Study

The limitations of the study could be seen in the literature, especially for the climate based design approach for urban furniture. Although there is a lot of research in the building sector in case of building energy simulations and climate analyses, smart urban furniture design lacks climate based design methods. The reason for this is the fabrication industry, which does not concentrate on site specific solutions. In contrast, the design method is to easily place fabricated urban furniture anywhere it is needed.

Since there is less research on smart urban furniture design methodology, the thesis study seeks a solution for a new research field. Therefore, while doing research to find a proper source for smart urban furniture design method was a burden.

Moreover, the psychologic condition of the human figure could not be calculated because of the plug in deficiencies.

5.2 Future Studies

The current thesis study draws attention to many points regarding the smart urban furniture design methodology. It provides a strategy and points out specific parameters that should be taken into account while designing or doing research. Since the recent literature does not respond to the rising needs of a new design method for smart urban furniture, this thesis study is going to present some information about this field. However, many parameters are open to be researched regarding the material quality and its influence on human comfort. Another important issue that should be concentrated on is the energy of smart technology devices on the SUFs. That is, many technological devices constitute a thermal energy which is important in terms of protecting these devices from excessive heat gain. Therefore, an analysis method should be improved in order to tackle with this problem.

The future is open for developments. The technological improvements in PV panel sector, the smart urban furniture need in cities, the use of electric devices are the main boosts for several developments in this field. As a result, more studies are going to be conducted in the future. Not only buildings, but also comparatively small structures are going to be a topic for analysis based design methods.

In summary, smart urban furniture is an inevitable result of the increasing need for the use of electrical devices outside our homes. This field is open for improvements and will have a direct influence to tackle with climate change in terms of helping to create zero carbon emission spaces in our cities.

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APPENDICES

A. Total Radiation Analysis for Alternative 6

January	113 kWh
February	246 kWh
March	575 kWh
April	689 kWh
May	847 kWh
June	930 kWh
July	1040 kWh
August	931 kWh
September	886 kWh
October	518 kWh
November	387 kWh
December	257 kWh

B. Total Sunlight Hours Analysis for Alternative 6

January	2727 hr
February	2702 hr
March	2956 hr
April	2591 hr
May	2613 hr
June	2428 hr
July	2558 hr
August	2579 hr
September	2815 hr
October	3027 hr
November	2710 hr
December	2620 hr