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REVIEW PAPER

OVERVIEW ON THE ROLE OF INTELLIGENT URBAN FURNITURE IN IMPROVING THE ENERGY AND ENVIRONMENTAL QUALITY OF PUBLIC SPACES

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ABSTRACT

The increasing prevalence of smart street furniture is a testament to the growing number of initiatives and companies that are creating objects connected to photovoltaic technology. They have emerged in a variety of forms, tailored to specific functions and modes of use, within the context of energy transition and technology. These innovations, in a variety of forms and functions, are designed to promote sustainability and address energy and environmental challenges, with the objective of reducing everyday power consumption and improving the planet's ecological state. This article presents a literature review of the field of street furniture, identifying key advances that have shaped its evolution and integration of innovative and smart technologies. It outlines the diverse types, modes of use, and contributions of street furniture to urban energy and ecological improvement, based on data from previous research. The results demonstrate that this type of furniture is still in development and that its benefits are sometimes of regional or even national importance, due to its contribution to solar energy production and environmental improvement. The range of innovative services offered by this type of furniture varies according to the specific product. These include smart lighting, WiFi connectivity, smartphone charging, illuminated advertising panels and so on. There is a strong focus on ensuring that this furniture is in keeping with the natural environment, with healthy materials, textures and shapes inspired by nature. This is important as the furniture can also act as a symbol of the city.

Keywords: public urban space, intelligent street furniture, energy efficiency, environmental quality, sustainability

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Introduction

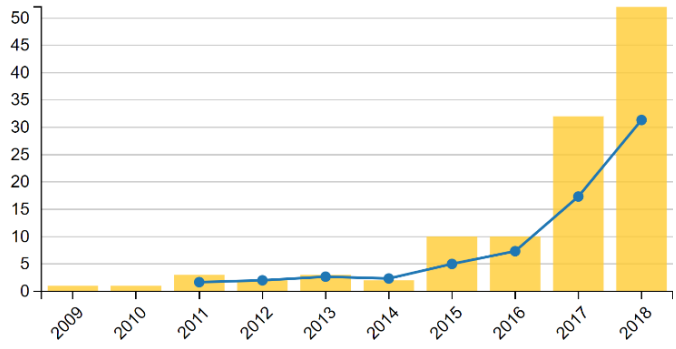
In the current era, the issues pertaining to energy conservation, global warming, and the comfort of users in both indoor and public spaces have compelled the market to rethink its strategies, with the aim of providing solutions that simultaneously ensure the wellbeing of users and energy efficiency across all areas, while always considering the concept of sustainability in favour of nature as a control and preventive strategy (Khelfa et al., 2024), seeing that the IPCC (Intergovernmental Panel on Climate Change) has determined that there was a 0.74°C temperature increase between 1906 and 2005 (Solomon et al., 2007). This is corroborated by global and continental models along with observations. While the extent of their contribution is unclear, urban areas have played a notable role in this trend (Trenberth et al., 2007; Khelfa et al., 2024)

Such urban public spaces are regarded as being of significant importance, facilitating integration of citizens into society and the formation of a collective culture and identity. They constitute the primary setting for social interaction and communication. Urban open spaces are referred to as 'third spaces' due to their function as gathering points for individuals outside of their domestic and occupational environments (Tereci & Atmaca, 2020). It is therefore important to consider the users of public spaces who lack the necessary protection and comfort to engage in a range of activities, including relaxation, recreation and even work (Khelifa, 2024).

In urban areas where the processes of pedestrianisation and densification have been ongoing for an extended period, the design of street furniture is intended to facilitate the activities of residents and the utilisation of public spaces. The concept of the open city emerged in the late 18th century as a result of significant urban developments. During the nineteenth century, these flourishing districts underwent a transformation, becoming showcases for a diverse array of Haussmann furniture from France and beyond. The style, functionality, and utilisation of this furniture were profoundly shaped by the era. These seats, bollards, litter bins, and candelabras have become emblematic of the distinctive character and urban landscape of cities (A'urba, Bordeaux Aquitaine urban planning agency, 2020).

Street furniture fulfils a variety of functions, thereby offering a degree of comfort to those who be present in urban areas. The process of global urbanisation, coupled with the rapid expansion of the population in most cities, has resulted in a shift in the demands and expectations placed on public spaces. The term "street furniture" encompasses then a range of newer urban infrastructure, including benches, lampposts, bus stops, bicycle parking, litter bins, and children's play areas. The advent of new design trends can be attributed to a confluence of factors, including urbanisation, rapid advances in technology and the growing demand for a diverse range of goods in street furniture. The quality of life of the urban population is enhanced by the integration of renewable energy technology into furniture design, which incorporates cutting-edge technological features (Başar, 2021).

Figure 1.
The upward trajectory of patent applications for intelligent furniture, as identified in the ESPACENET database comprising 114 published patent applications across the globe
Source: (Krejcar et al., 2019).



In consideration of the full range of needs and expectations, street furniture powered by renewable energy sources is becoming increasingly prevalent. The latest generation of street furniture, which incorporates both technology and renewable energy, is regarded as intelligent, sustainable and environmentally friendly. The use of renewable energy as a power source in street furniture is becoming increasingly common in major cities around the world (Attmann, 2010). Examples of such products include interactive bus stops, solar-powered charging stations, sports equipment in public spaces, giant billboards, kiosks, public benches, and bicycle racks. Additionally, various types of renewable energy sources, including solar energy, wind power, geothermal energy, biomass energy, hydropower, fuel cells, and hybrid systems, are being employed to power this new generation of street furniture (Alotaibi et al., 2023). In recent years, there has been a notable increase in patent activity worldwide pertaining to intelligent furniture, with a particular focus on the generation of clean and renewable energy. This is illustrated in (Fig-

ure 1), which serves to demonstrate the relevance and importance of this topic on a global scale. So, the objective of this present study is to provide an overview of intelligent street furniture, including an examination of its various types, modes of use, and contribution to energy efficiency and transition, as well as its role in reducing the ecological footprint.

This article represents a comprehensive review and synthesis of extant literature on the subject matter. A range of references were collected, read, selected and analysed according to established criteria. The sources consulted included books, scientific journals' articles, theses, proceedings and websites. Subsequently, the field of street furniture was identified, along with the advances that have affected this field up to its integration by smart technologies. Furthermore, an investigation was conducted into the various types, modes of utilisation and contribution of street furniture to the enhancement of urban spaces in terms of energy efficiency and ecological sustainability.

The research was not conducted within a particular context; rather, it was based on the findings of prior research conducted in various locations around the globe by a diverse range of multinational authors. The majority of the scientific documents under review are written in English, although there are a few exceptions, including some documents written in French.

Documents and research published before 2005 have been excluded, as well as those relating to street furniture, but which did not deal with energy or environmental aspects, like those relating to aesthetic, social and economic aspects, as example.

A synthesis of the findings from the disparate research studies situated within this context has yielded the following results.

Chapter 1: The identification of 'intelligent urban furniture'

The function of furniture is to provide comfort, information and services to those visiting or being in urban environments. The term encompasses a diverse array of objects, including public lighting, street cleaning equipment, grilles at the base of trees, planters, litter bins and toilets, rest and shelter furniture for travellers, traffic equipment such as traffic lights, mirrors, road signs and pavement equipment, and information spaces in urban centres (Morsi et al., 2016; Grabiec et al., 2022).

In the contemporary era, street furniture constitutes an indispensable component of urban design. Its approach, which draws on a number of disciplines, naturally takes account of development issues and helps to redefine spaces through the quality of the landscape, the harmonisation of colours, the treatment of surfaces and coverings, signage and support for travel, while meeting the objectives of ergonomics and user comfort (A'urba, Bordeaux Aquitaine urban planning agency, 2020).

The concept of street furniture has undergone significant evolution since the introduction of the first bus shelter in 1964. Technological advances, including intelligent road signs, interactive displays, dynamic public lighting and other innovations, are transforming the architectural landscape of our cities, fostering greater connectivity on a daily basis. Furthermore, intelligent street furniture incorporates clean energy, thereby becoming an integral component of contemporary sustainable development strategies. Solar energy, a free, inexhaustible, and environmentally benign source of energy, is becoming increasingly accessible due to its ease of use, thereby opening up new possibilities. Furniture is becoming more autonomous and continuously evolving to offer an expanding range of services without the necessity for earthworks or trenches (Silicontile, 2018).

Chapter 2: Types of 'intelligent urban furniture'

A comprehensive literature review was conducted, with the objective of collating projects and built examples of solar and smart street furniture. The examples identified resulted in a preliminary classification of the various types of street furniture that can be designed and integrated with solar and smart technologies. The solar street furniture identified is presented and classified with the examples presented below. The diverse case studies demonstrate that street furniture, encompassing its various categories, can facilitate solar energy generation and diminish the ecological footprint through two principal avenues: firstly, by reducing the reliance on fossil fuels for energy, and secondly, by manufacturing these products using environmentally benign and sustainable materials.

1. Canopies

The Bay Area Rapid Transit (BART) system in California, USA, comprises five lines and 43 stops distributed across four counties. The system carries approximately 320,000 passengers per day, making it the fifth most popular system in the United States.

Given the considerable volume of traffic and the resulting energy consumption, it was evident that the installation of an energy-saving device would be beneficial in reducing both energy costs and the environmental burden. This high-speed station in San Francisco, Union City, elected to utilise Onyx Solar's glass photovoltaic modules in the form of an aesthetically pleasing photovoltaic canopy (Belnor Engineering, 2017).

2. Pergolas

A solar pergola is a structure comprising solar panels that are used to shelter a designated space for relaxation in a park. In addition to providing a means of generating renewable energy, it offers a novel approach to harnessing solar electricity. It provides a transparent and distinctive option for utilising solar energy while individuals repose beneath it.

Figure 2.
Lateral view of the pergola of Barcelona. Source: (Lucera website, 2024).

The generation of solar energy by means of pergolas has the dual benefit of creating a pleasant and useful outdoor living space while simultaneously powering part or all of the park and reducing additional utility costs (Hemalatha et al., 2014). The integration of solar panels into structures is being pursued as a means of both harnessing solar energy and encouraging sustainable development.

The open structure and aesthetic appeal of pergolas make them a suitable location for the installation of solar panels, which can capture sunlight and convert it into clean, renewable electricity, thereby reducing reliance on non-renewable energy resources.

As an import example, the pergola in Barcelona, which is illustrated in (Figure 2), is considered as the largest urban solar power plant in Europe, it comprised a panel surface area of 3,410 m² and was constructed on the expansive pergola beneath which the Barcelona Forum was held in 2004. This specimen is arguably the most widely recognized. The innovative design of this pergola has imbued the solar power plant to which it is attached with a grandeur that has rendered it a prominent symbol of the city. It can also be regarded as an exemplar of the manner in which urban photovoltaic energy is currently being utilised in Spain. This energy is frequently deployed in new buildings, often with a symbolic message, while extensive installation in our cities remains a distant prospect (Frolova et al., 2015).

3. Carports

In collaboration with the Scottish Government, Aviva which is a UK's leading diversified insurer across Insurance, Wealth and Retirement, in the UK, Ireland and Canada, has inaugurated one of the United Kingdom's most expansive solar carports and energy storage facilities at its Perth office.

Figure 3.
Aerial view of the AVIVA project of 342 parking spaces sheltered by solar panels. Source: (AVIVA, 2020).

The facility which is demonstrated in (Figure 3) encompasses 342 parking spaces and encompasses 50 charging stations for electric vehicles. Aviva's facility will be powered by cutting-edge Tesla Power pack technology, with an anticipated combined annual reduction in carbon emissions of almost 400 tonnes. This is equivalent to the annual

carbon footprint of more than 500 homes or that of a small town. Consequently, the Aviva office in Perth is able to disconnect from the grid for a period of five hours each day, when the national grid is under the greatest strain. Any surplus energy will be stored in the battery for subsequent use or exported to the grid (AVIVA, 2020).

4. Solar trees

The Centre for Grants and International Projects at An-Najah National University has announced the commencement of the inaugural phase of the 'off-grid solar tree' project, which has a capacity of 3.18 kilowatts. It is noteworthy that this solar tree initiative is the inaugural project of its kind in Palestine. In addition to providing shade, the 3.5-metre-high tree also employs solar energy to generate electricity, which can be used to power 20 LED lights and 100 electronic devices, including wheelchairs, mobile phones and laptops. Furthermore, the electricity generated can be used to regulate the timing of night-time lighting. As a result of this pilot project and others already implemented, the institution will be able to reduce its annual CO2 emissions by 550 tonnes. In addition, the project will lead to a reduction in diesel fuel consumption, which will in turn improve the service provided to students and employees during periods of prolonged power cuts (ENI CBC Med, 2022).

A salient feature of urban settlements is the elevated temperature they typically exhibit in comparison to the adjacent suburbs. The underlying cause of this phenomenon can be attributed to a range of contributing factors. One such factor is the considerable increase in heat gain observed in pavements and building walls. The rate of warming in cities across the globe is approximately twice that of the global average. This phenomenon can be attributed to two key factors: rapid urbanisation and the urban heat island effect. By 2100, it is projected that many cities around the world could experience a temperature increase of 4°C if greenhouse gas emissions continue at current levels (U.N.E.P, 2023). In response to this necessity, a consortium of Japanese designers has created a concept for street furniture that provides cooling spaces in publicly accessible areas. This design, which takes the form of a wooden structure, has been developed with consideration of the contextual value of the surrounding area, and offers people a place to rest and a refreshment service. The structure may be described as a 'cool point'. The dimensions of the basement are 4.8 m by 4.8 m, while the roof measures 4 m by 4 m. The photovoltaic panels, situated at the top of the structure, provide energy directly to the cooling units that are suspended beneath the roof. The cooling units emit water vapour directly onto the users who are seated underneath, thereby cooling them. As a result of the roof's solar protection, the users are not directly affected by the sun's rays (Nikken Sekkei Co, 2020).

5. Bus stops

Solar-powered bus stops, such as the one shown in (Figure 4), have the potential to disseminate a variety of information, including advertising, public transport updates, tourist information, weather warnings and even access to email. A similar structure has been developed by researchers at the Massachusetts Institute of Technology's SENSEable City Laboratory (Tuvie Design website, 2009).

The EyeStop project is an interactive bus stop initiative developed for the city of Florence, Italy. It is powered by solar energy and is equipped with sensors that monitor air pollution and weather changes. The installation incorporates smart maps and touch screens, enabling users to access route information simply by touching the station they wish to visit (Willemijn, 2014).

The functionality of modern passenger information systems and journey planners is contingent upon the availability of a comprehensive digital representation of the stops and transportation hubs in question, without which the aforementioned systems and planners are unable to function correctly. The CEN Trans-model data archetypal and the associated IFOPT data interchange standard provide a framework for the description of transport systems, including bus stops, for use in computer models. In the Trans-model data model, a single bus stop is represented as a 'Stop Point', whereas a grouping of nearby bus stops is represented as a Stop Area or Stop Place.

Figure 4.
An example of solar-powered bus stops. Source: (Cognimetrica website, 2024).

In addition, OpenStreetMap has developed a model for representing bus stops in a consistent manner. Furthermore, in the United Kingdom, the NaPTAN database, which is accessible as open data from (data.gov.uk), contains comprehensive information on public transport access points, including details of 350,000 bus stops. Also, Google developed the General Transit Feed Specification (GTFS) standard, which established a simple, widely used data interchange standard for public transport schedules. The GTFS standard provides a table containing a list of stop points, along with the relevant name and location data for each bus stop (David & Chalon, 2010).

6. Benches

The advent of wireless technology, coupled with the proliferation of unlimited access to information on the Internet and data collection and dissemination applications, has enabled individuals to construct communication networks that were previously unimaginable. EnGoPlanet is a consequence of this technological revolution, which is improving public services through the Internet of Things (IoT), waste management, transport and energy management (EnGoPlanet, 2018).

The EnGoPlanet intelligent sunbed has been designed with the contemporary, connected customer in mind. The solar panels integrated into this product provide a source of electricity for portable electronic devices. The energy is transmitted by the Smart Solar Bench via USB or hotspots. It responds to customer demand for WiFi and low-voltage charging in a way that is both functional and innovative.

Figure 5.
The Fluid Cube and City Snake intelligent street furniture in Hungary.
Source: (McNulty-Kowal, 2021).

The bench's classic design conceals a multitude of functions, including the ability to power white, blue, green, or red LED lighting via the integrated solar panels. The bench's sustainable design utilizes renewable energy sources that are affordable, safe, and environmentally friendly, minimizing its environmental impact (EnGoPlanet, 2018).

The Fluid Cube and City Snake, shown in the (Figure 5), are intelligent street furniture in Hungary designed by an architectural office, featuring two interconnectable components. This gives the furniture a modular advantage, designed for both public and educational use. It is a bench with integrated technical services, featuring a primary cube that is 9 meters long. In bad weather, the structure offers a convenient refuge for passersby. Two parallel benches are placed next to the main cube.

The City Snake is a 7-foot outdoor bench. 5 metres long, its curved shape offers diverse seating and positioning options. The Fluid Cube and City Snake use photovoltaic panels for energy. The main cube has solar cells, while the City Snake features conventional solar panels on its seats (Grillo, 2019; Artform urban furniture website, 2020).

7. Street lighting

Solar street lighting is defined as a form of outdoor illumination utilising the energy provided by the sun. The popularity of solar lighting has increased markedly in recent years, reflecting a growing demand for environmentally friendly and energy-efficient lighting solutions.

In addition to the economic benefits, the street solar lighting provides considerable environmental advantages. The utilisation of this sustainable and inexhaustible resource can assist in the reduction of the carbon footprint associated, and also in energy savings and productions (Sengupta et al., 2021). Furthermore, the installation of solar lighting does not necessitate any significant physical disruption, as there is no requirement to connect it to the electricity grid. This makes it an optimal solution for ecologically sensitive areas, parks, and holy sites (United nations, 2021).

In the summer of 2006, five prototypes of photovoltaic lighting based on the Stapelia design were created and installed in the garden of the ENEA (Italian National Agency for New Technologies, Energy and the Environment) research centre in Portici. The Stapelia, whose shape and nomenclature are inspired by the structure of the eponymous tropical flower, can be integrated into locations of considerable aesthetic value.

Figure 6.
photovoltaic lighting based on the Stapelia design. Source: (Scognamiglio et al., 2007).

The fundamental concept underlying the geometry, which is based on a pentagon, is that one or more elements, such as flowers, can be strategically positioned where a power supply or site enhancement is required. The most crucial aspect of this photovoltaic component (Figure 6) is an appropriate design, which must ensure both good integration into the surrounding environment and a pleasing balance between the component's various roles. An optimisation process is currently underway at various Enea units, focusing on the individual elements incorporated into the design of Stapelia. This process monitors the component's actual performance, including lighting and photovoltaic energy production (Scognamiglio et al., 2007).

8. Solar Rubbish Bins

Photovoltaic (PV) panels facilitate the conversion of solar radiation into energy, which is subsequently stored in batteries to power the solar bins. The internal compactor of the bin is then powered by the previously conserved energy. The waste is compressed within the bin, thereby reducing its volume and allowing it to accommodate a greater quantity of waste. The utilisation of solar energy in refuse bins offers a number of advantages. Firstly, the elimination of waste transportation reduces the carbon impact of waste collection, which is typically achieved through the use of diesel-powered lorries. Secondly, the reduction in the frequency of refuse collections, enabled by the compaction of waste, allows for the containment of a greater volume of waste within a given area. Consequently, the number of lorries required for waste collection is reduced, which in turn leads to a reduction in the associated transportation costs. The compaction of debris also prevents its dispersion by wind, which can contribute to a reduction in littering (Orwak-Compactors, 2023).

The all-aforementioned examples demonstrate that street furniture projects can assume regional or countrywide importance, or provide sufficient energy for a facility or an administrative or university centre, or even make a significant contribution to the national energy economy. Furthermore, intelligent solar street furniture has the potential to become a monumental symbol and work of art, thereby enhancing the aesthetic value and charm of public spaces, as exemplified by the Barcelona pergola. The addition of street furniture can enhance the visual appeal of public spaces, fostering a more attractive and welcoming environment. Furthermore, the incorporation of street furniture can serve to establish a focal point within an area, directing the gaze and contributing to the definition of the character of a space, thereby conferring upon it a distinctive identity. Additionally, there is a notable interest in the development of street furniture that is in harmony with the natural environment and the surrounding context. This approach aims to leverage the benefits of such designs while avoiding any detrimental impact upon the quality of the landscape or the introduction of visual pollution. This is achieved through the utilisation of natural, floral and faunal forms, as well as their associated geometries, colours and textures, in the creation of new designs.

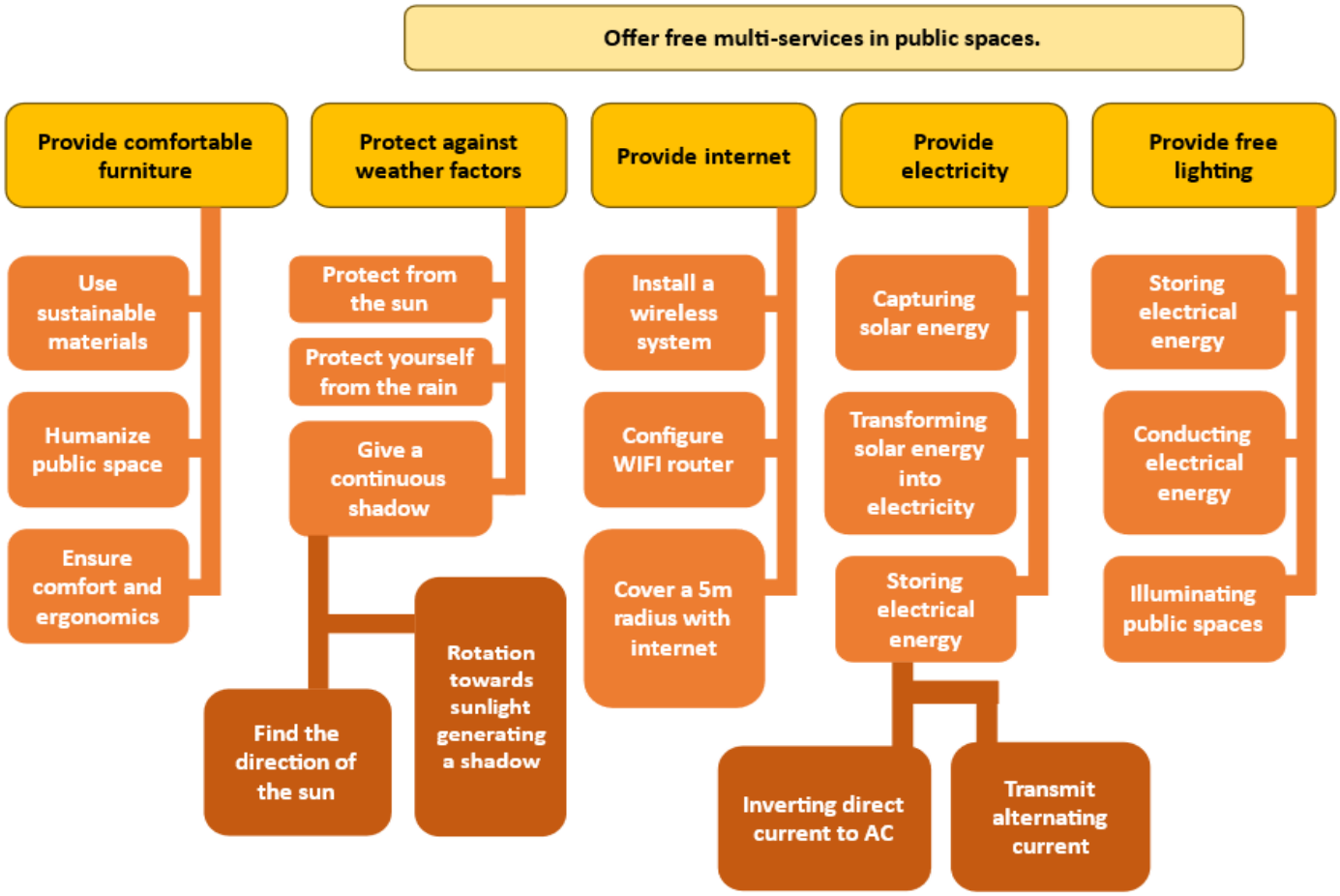
Chapter 4: Modes of use of smart solar street furniture

Following the examination of previous literature and examples, and also based on a comprehensive and effective interview conducted by Avila et al. (2018) to ascertain the needs and specifications of prospective users, the diagrammatic representation in (Figure 7), which offered a summary of the theoretical functional division of solar furniture, enabled the identification of the final sub-function of the innovative furniture design, thus affording the opportunity to gain a comprehensive understanding of the constituent parts and their functional interrelationships, thereby informing the design decision-making process.

Over the past century, the two principal drivers of innovation have been sustainability and technology. The concept of smart solar furniture represents a convergence of these two distinct

movements, offering a range of potential benefits to individuals, organisations and communities. The term "smart solar furniture" is used to describe any type of furniture that is equipped with solar panels and other intelligent elements. Such items may take the form of benches, street lamps, charging stations or litter bins. Such furniture is powered by renewable energy sources, thereby offering a greener alternative to conventional furniture. The utilisation of smart furniture can facilitate the realisation of a more sustainable future, through the harnessing of solar power in order to reduce the carbon impact. Furthermore, the utilisation of smart furniture can result in long-term financial savings, as it does not require the input of electricity from the grid. Instead, it draws its energy from solar sources, thereby reducing the associated utility costs. Furthermore, some smart solar street furniture has the potential to generate revenue through advertising or other services, which could assist in covering installation costs (Urban Elements, 2023).

Figure 7.
Modes of use of smart solar street furniture.
Source: Author, 2024.



The practical services and ease of use offered by smart solar furniture are two of its most notable features. Solar-powered charging stations, for instance, provide a convenient means of recharging mobile phones and other electronic devices while on the move, eliminating the need for a conventional electrical socket.

Smart benches with Wi-Fi connectivity and USB charging sockets offer a comfortable and convenient place to work or rest while remaining connected to the internet and charging electronic devices (Dean, 2023). Furthermore, smart solar furniture has the potential to facilitate community engagement and social interaction. The installation of smart benches and other forms of outdoor seating encourages people to spend time in public spaces, facilitating social interaction and engagement. These furnishings provide a comfortable and practical space for individuals or groups to sit or work, offering protection from inclement weather such as sunlight and rain.

Additionally, they offer comfortable and ergonomic seating, enhancing the overall experience of the public realm. This can contribute to the development of a more vibrant and connected community. Sensors installed on smart street furniture can collect vital data on issues such as air quality, noise levels and pedestrian traffic. This data can then be used by cities and businesses to gain insights into the wishes and behaviour of their consumers. In turn, this allows cities and businesses to make informed decisions about how to improve the user experience and promote sustainability by collecting data on how people use intelligent furniture.

Conclusion

Public spaces are of significant importance as locations utilized by the majority of people for social interaction, relaxation and enjoyment. It is imperative that these areas be safeguarded from all forms of pollution, as they are regarded as being environmentally pristine. The implementation of renewable energy technologies in these locations will, therefore, serve to encourage public engagement and maintain the parks as pollution-free environments. Moreover, the technology has the potential to disseminate through the adaptation of its applications to public spaces. This study focuses on the concept of 'intelligent' solar street furniture, which can be defined as street furniture that incorporates solar technology. A number of initiatives and concrete applications, in addition to a growing number of patents, provide evidence of the growing interest in this field. The role of street furniture has evolved beyond its traditional applications, which included street lighting, street cleaning equipment, tree grates, planters, litter bins and sanitary facilities, rest and shelter furniture for travellers. It is now being employed in innovative ways, where street furniture is used as a producer and generator of renewable solar energy, is autonomous, and provides intelligent services, such as the ability to recharge devices using USB or wireless charging ports on benches in bus stops or in public spaces. In addition to the aforementioned charging ports, these benches are equipped with Wi-Fi connectivity, built-in environmental sensors, advertising panels, and displays that provide information or directions regarding the location being visited or traversed. Intelligent solar street furniture is available in a multitude of forms and designs, tailored to specific functions and requirements. It can assume significance at the local, regional, or national levels. It can even serve as a symbol of the city. Its evolution is ongoing, with an increasing alignment with the surrounding urban fabric, offering users enhanced comfort, energy efficiency, and the highest environmental quality.

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