Smart solar urban furniture: design, application, limits and potentials

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Abstract: Smart urban street furniture is a growing reality with several projects and companies producing objects integrated with photovoltaic technologies. Smart bus stops, pergolas, canopies, carports, solar trees, solar benches are just some examples of the objects available today. Some of the opportunities offered by smart urban street furniture are self-powered rechargeable docks for smartphones or other devices, information screens, public lighting, free wi-fi, rechargeable stations for electric vehicles. They can be used to collect big data, offering opportunities for our daily lives, also after the covid-19 pandemic. The aim of this research is to provide a classification of the most important solar urban street furniture, to understand the strategies adopted in case studies and to understand the main problems related to the adoption of these devices and where future research should focus. The methodology involved a selection of international case studies in important urban contexts to gather information as: architectural integration, context sensitivity, system visibility. The preliminary results indicate that potential limits to the application of these technologies are urban morphology and lack of design of some solutions. This study can be useful to understand the potential use of these products in our territory.

Keywords: Smart street furniture; Smart city; Photovoltaics; Sustainable design.

1. Smart and solar urban furniture

The use of building integrated photovoltaics (BIPV) in urban elements is a reality. There are many examples of PV technology integrated also in urban furniture or vehicles, boosted by the BIPV modules adaptability to end-user’s requirements regarding transparency, colour or glass treatments (Rico et al., 2019).

A recently published research demonstrated a significative increase in patent activity around the world for Smart Furniture. The number of patents increased from less than 5 in 2009 to more than 50 in 2018 (Krejcar et al., 2019). This research was focused on the identification of a unique definition for the term smart furniture based on literature and patent analysis. The databases investigated included SCOPUS, Web of Science, and IEEE Xplore and ESPACENT for the patents. The chosen period was between 1998 and 2017. The results indicated that smart furniture should be defined as “designed, networked furniture that is equipped with an intelligent system or is controller operated with the user's

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data and energy sources" (Krejcar et al., 2019). Thus, smart furniture should be implemented with sensors and actuators able to adapt to the users' needs.

This research is focused on "smart" solar urban furniture, thus on urban furniture implementing solar technologies. There is a growing interest on this topic demonstrated by a number of projects and real-world applications. Amongst them, The Land Art Generator Initiative, a design competition held in 2019, gathered entrants from around the world to create a renewable energy-producing artwork for the UAE's Masdar City in Abu Dhabi. The book including the most significative design proposals comprises more than 70 projects demonstrating the aesthetic possibilities of renewable energy infrastructures. These projects involved spaces for recreation and contemplation, illustrating the possibilities of living well in a post-carbon future (Monoian & Ferry, 2020).

As it is well known, there are several types of solar urban furniture. Besides that, we should consider that we might have self-powered as well as grid-connected devices. Self-powered smart urban street furniture can help cities and communities to increase the attractivity of public spaces by providing public services, information, and connectivity, while at the same time enabling the collection of valuable data for optimizing processes and reducing costs (Müller, 2017). Several examples of smart street furniture solutions can be found all around the world. Goals of smart street furniture are to make life easier for citizens and visitors, to optimize the management of public infrastructure, to provide connectivity such as free Wi-Fi and so forth. Digital signs and screens can provide information to citizens and users on public transportation availability or traffic congestion; smart benches can be used as rechargeable docks for smartphones; bus stops can spread localized Wi-Fi signal.

Given the current state of the art of the development of smart solar urban furniture and their use, it seems necessary to provide a classification of the different objects we may encounter globally, while providing some practical examples. Aim of this research is to reflect on potential applications in the Pacific regions and in particular in Auckland, New Zealand.

2. Classification of solar urban furniture

A literature review has been performed on books, journal articles, conference papers and websites collecting projects and built examples of solar urban furniture. More than 80 examples have been found, leading to a preliminary classification of the different types of urban furniture that can be designed and integrated with solar and smart technologies. Solar urban furniture that have been identified are:

- Canopies
- Pergolas
- Carports
- Bus stops
- Benches
- Solar trees
- Street lighting
- Experimental objects

The following section describes some examples amongst those included in the research. Each case study described below is indicative of one of the different types of smart solar urban furniture listed above.

2.1. Canopies

A typical example of solar canopy is the Union City station project in San Francisco, USA. The so-called BART station system carries over 320,000 passengers daily, placing it in the 5th position of the most used infrastructures in the United States. Given the heavy traffic and massive energy consumption, it has been decided to refurbish the existing canopy comprised of 800 crystalline silicon photovoltaic glass modules. This is a large installation of PV modules on a “V” shaped metal roof structure. The panels are visible from the people walking below the structure and their pattern also contribute to the solar shading of the area. They are installed on glass panels. The context of this installation might be considered of low sensitivity because it is a civil infrastructure. The architectural integration is provided by the fact that the panels constitute the roof of the structure. Another famous photovoltaic canopy is the one at the North Sydney Coal Loader which is part of a large project of urban regeneration. In this case the metal structure of the canopy is linear (squared arches). PV panels are distributed only on a small portion of the canopy and they are almost flat (non-tilted). The visibility of the panels is high, but they constitute the roof of the structure. Since the panels are not distributed on the entire structure they don’t change the perception of the light metal structure, thus resulting in a balanced architectural integration.

2.2. Pergolas

It is well known that photovoltaic systems can be installed on top of pergolas. In Europe, perhaps the best known example is the huge pergola under which the Barcelona Forum was held in 2004. This was the biggest urban photovoltaic plant in Europe in 2004 (Frolova et al., 2015). This is another large urban installation concentrated on a single structure. The visual impact of the structure is high as it is installed in front of the sea (a sensible context). However, the whole area is a urban park clad in concrete and surrounded by contemporary buildings. In such a context the huge structure is just one of the available infrastructures and it is integrated with the context. Smaller structure like kiosks can be conceived as mart urban furniture creating also a network of digital urban nodes that facilitate citizen city communication and interaction.

2.3. Carports

Amongst the several project and prototypes designed and built in the last few years, an example of a carport could be the Volvo Pure Tension Pavilion. This was a tensile pavilion covered in solar panels that could be used to charge an electric car and then folded up to fit in its boot. It was designed by Synthesis Design + Architecture with Buro Happold engineers for the car brand Volvo to showcase its electric hybrid V60 car during a promotional tour of Italy in 2013. The fabric surface, made of from a vinyl encapsulated polyester mesh membrane, was implemented with 252 flexible photovoltaic panels. According to the external conditions, a power transmission controller automatically turned off the panels collecting least energy to ensure maximum power generation, whatever the pavilion's location. Power produced by the panels was fed through wiring integrated into the fabric skin into a portable battery to charge the car. In optimum sun conditions the systems generated 450W of power which were able to recharge a fully depleted car battery in about 12 hours. This was a temporary (removable) installation where thin-film solar cells were integrated on a membrane. Visibility of the cells was very high as they covered almost the entire surface of the carport. However, solar cells were custom designed according to the fluid form of the object. Context sensitivity was variable according to the place of installation. Anyhow, the special form (and removability) of the pavilion was suitable for different context, even for temporary installations in historic centres.

2.4. Bus stops

There are several example of smart bus stops projects and prototypes. Solar bus stops can be used to transmit information such as, advertisements, information on the public transit, but also touristic information, weather alerts, e-mail access and more. A similar bus stop has been developed by researchers at the SENSEable City Lab of the Massachusetts Institute of Technology. EyeStop is a project for an interactive bus stop designed for the city of Florence, Italy. Eyestop project is powered by sunlight and can detect air pollutants and weather changes. The bus stop is integrated with smart maps and touchscreens. The users just have to tap on the station they want to go and the screen will automatically show them which route they can follow. The screen shows real time information aiming at keeping the users up to date about any possible obstacles (Willemijn, 2014). The bus stop is designed as a single piece of curved glass where all the technologies are integrated in. This object was conceived as a piece of industrial design. The use of glass and the transparency of the structure was chosen for an adaptability to sensitive historical context like Florence.

2.5. Benches

In the last few years several start-ups started offering new smart urban furniture. They employed the IoT technology to create small urban furniture able to provide different services. Some examples are the US start-up and MIT spin-off "Changing Environments Inc." which produced Soofa Bench and Soofa Sign, (Müller, 2017). Hundreds of these Soofa benches have been installed in 65 different cities in the US and Canada by mid-2017. These are simple benches made of steel and timber with a solar panel installed in the middle. The solar panel, in this case, is not part of the bench as the people cannot sit on top of it. The design is functional but basic and the visibility of the PV panel is high due to its position. The architectural integration of the panel is also low as the panel is just placed on top of the bench.

The installation of the new solar street furniture on KAUST campus in Saudi Arabia has been completed in 2020. This is a circular outdoor seating, incorporating flexible, lightweight and transparent solar technologies developed by King Abdullah University of Science and Technology (KAUST) Solar Center (Solar Novus Today, 2020). The seating is shaped as a circular object where PV panels are placed on the external curved surfaces. These modules are constituted by organic photovoltaics (OPV) and they are semi-transparent. Due to its shape the object is highly visible in an urban context. However, the integration of PVs with the form of the bench is achieved through the flexibility of the adopted cells which also merge into the design.

2.6. Solar trees

Experiments and prototypes of tree-like structures have become very popular in the last years. The goal is to utilize the minimum land for maximum solar power generation. In solar trees, solar panels are arranged along the branches of a tree-like structure. Each node should only have one solar panel (e.g. in a spiral phyllotaxy arrangement). The aim is that panels avoid shading from each other and each panel gets a good share of solar energy. In some arrangements, branches and solar panels follow Fibonacci pattern (Gangwar et al., 2019). This configuration allows panels to receive solar energy in different directions, thus making use of sunlight throughout the day. In this way, a solar tree becomes more efficient and also the land requirement of installing it reduces as compared to installation of conventional panels (Gangwar et al., 2019). A famous solar tree has been designed in 2007 by Ross Lovegrove. An exemplar was installed in Piazza Gae Aulenti, in Milan, Italy (Figure 1). Solar trees are often characterized by a high visibility of the panels which are generally optimized for the maximum solar power generation. An achievement of this project is the form of the “leaves” which are not just holding standard PV panels but are custom designed according to the overall design of the structure.

2.7. Street lighting

Another type of urban furniture in which solar technologies can be incorporated is street lighting. An early prototype of PV lighting was built and installed in summer 2006 in the garden of the ENEA (Italian National Agency for New Technologies, the Energy and the Environment) Research Centre in Portici, Italy. The prototype was called Stapelia following the homonymous tropical flower. The geometry of this PV lighting was based on a pentagon, and the basic idea was that one or more elements can be installed where an electrical supply is required (Scognamiglio et al., 2007). This type of street lighting with architectural integrated PV seems not to be very common. Today solar street lighting products are available everywhere. PV street lighting are installed along important streets in many European countries and similar products are also sold in New Zealand. They are highly visible objects. However, these products need a lot of design and their visual impact is still not adequately optimized

2.8. Experimental projects

Experimentation is always very important to find innovative solution, especially at the urban scale where problems of overshadowing may arise. Joseph Cory, designer of Geotectura Studio with the help of the aerospace engineer Pini Gurfil designed floating solar balloons (SunHopes) capable of capturing the energy from the sun even in those urbanized areas where high-density would make the positioning of traditional solar panels practically impossible. This technology can also be placed in desert areas, in islands or in forests. In addition, the quick and easy assembly of this device makes it suitable for emergency situations. SunHopes consists of a control panel, a supply cable for helium, a power cable and a flask filled with helium. The latter is also covered with a fabric coated with thin film, waterproof, elastic and UV-resistant photovoltaic solar cells. The PV coating was made using a particular material made up of semiconductor metal titanium dioxide nanoparticles coated either with cadmium sulphide or with cadmium selenide. Finally, these modular platforms are hooked to the ground with a system of cables that allow the balloons to be supplied with gas and, at the same time, to transfer the energy to the ground (Chino, 2018). Although highly visible objects, these are special designs that might be easily integrated in different contexts due to their decontextualized form (Figure 1).

Figure 1: from left Solar Tree by Ross Lovegrove; SunHopes project. (Source: Geotectura Studio)

3. Aims, potentials and limits of smart solar urban furniture

Why should our cities and communities consider "smart" solar urban furniture? Benefits often stated by professionals in the smart cities business are (Müller, 2017):

- Free solar-powered charging docks for smartphones and other portable devices;
- Free Wi-Fi connectivity;
- Information delivered via screens and interactive tools;
- Education on renewable energy;
- Saving energy consumed by electric powered street furniture (public);
- Saving energy consumed by households and companies (private);
- Collecting big data to improve public services (e.g. pedestrian traffic, use of public facilities, comparison of different locations; weather data);
- Advertisement.

It should be noted that smart furniture continues providing their services also during periods of lockdown as it happened during the Covid-19 pandemic. Hence, if connected to the grid, they can generate electricity for other purposes.

3.1. Critical aspects

A problem which is usually highlighted by the press and by the people who are sceptical of these technologies, is the possibility of stealing solar panels. Although this is a real problem (Feek, 2017), special joints have been studied over the years to reduce this risk (Cabanillas Saldana, 2012). Furthermore, the integration in glass panels or other materials embedded in the furniture can reduce this issue. Vandalism might be another issue, but education may help in reducing this phenomenon.

One of the main issues when dealing with photovoltaics is the visual impact of these technologies on buildings and the environment. 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 customised design and following guidelines developed by the councils (Munari Probst & Roecker, 2012). Although many of the objects described in section 2 of this paper showed a high level of architectural integration of smart technologies, some of the commercial products (e.g. street lights, solar benches) showed a lack of design and a high visual impact of PV technologies. This means that there is room for architects and designer to improve the quality of these objects.

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). In fact, the third critical aspect is the position of the furniture within the urban context. 3D city models combining terrain reliefs, buildings, city furniture (and possibly vegetation) are increasingly used to simulate the solar irradiance on built surfaces, and therefore the solar energy generation. For new urban projects built in dense urban areas, it is essential to consider the existing surrounding buildings and the possible external shadings and reflexions. 3D city models are available for an increasing number of cities (especially the open standard CityGML). 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 optimising the solar utilisation (Lundgren et al., 2018) as well as the position of solar urban furniture within the urban context to avoid overshadowed areas.

According to Lobaccaro (2019) a correct approach to the design of solar plants in the urban context follows a protocol that evaluates the architectural visibility, sensitivity and quality of solar installation. “Architectural integration quality” is the assessment of the quality of integration of solar systems. According to this evaluation, in order to perceive the system as integrated, it has to be designed as an integral part of the architecture or of the urban settlement. Geometry, materiality and modularity are assessed. “Urban context critical issue” evaluates how the quality requirements for architectural integration have been adapted to the local situation, specifically to the sensitivity of the urban area and the visibility of the furniture. “Context sensitivity” is the socio-cultural value of the urban zone where the urban furniture is located. Historical centres are generally ranked as high-sensitive areas while industrial areas or low-quality suburbs are ranked as low-sensitive. “The system visibility” assesses the perception of solar systems from the public spaces. It can be defined as “close visibility” from an urban perspective, or “remote visibility” from a far observation point (Lobaccaro et al., 2019).

A preliminary survey of the selected projects and built examples has been carried out following the three above mentioned criteria: “architectural integration”, “context sensitivity” and “system visibility”. Figure 2 shows the results of this preliminary investigation. It is evident that canopies and pergolas constitute the majority of the case studies. On the vertical axis is the number of identified objects for each type of solar urban furniture. Overall, for both categories there seems to be a high level of architectural integration in the design. They both have been installed in contexts with an average to low level of sensitivity, thus mainly in suburbs, industrial areas or modern city centres. The solar system visibility seems to be average to low, highlighting once again the high level of architectural integration. There seem to be furniture that need more attention in the design, like street lighting and solar trees which present a high level of system visibility.

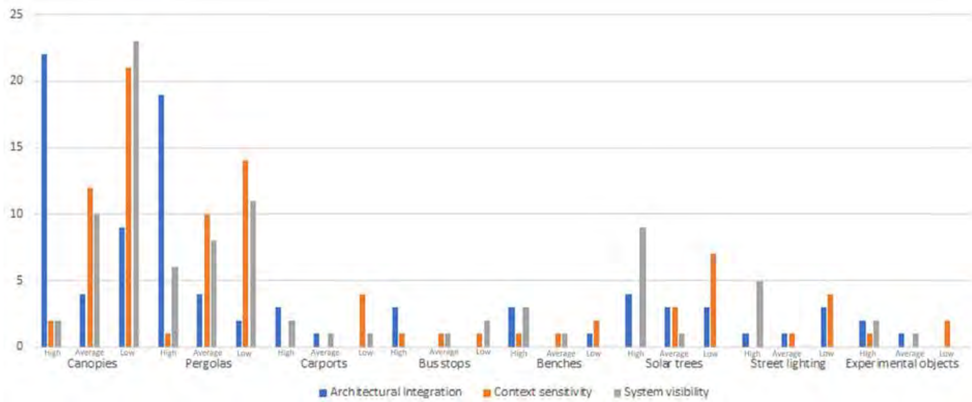

Figure 2: evaluation of the design of the selected case studies

Most of case studies are installed in plazas, along streets and in urban parks. Some of them are part of larger projects of urban regeneration (e.g. North Sydney Coal Loader). In general, a lower visibility of the system is associated to a higher level of architectural integration. The most successful projects, from this point of view, seem to be the smallest ones: bus stops or custom designed benches (e.g. KAUST), in particular where solar panels are highly integrated in the design and not just placed on top of the object. It has to be noted that solar benches can generate energy when people are not sitting on them. Further investigation is needed to analyse only the built case studies as many objects are commercial products but their applications are still sporadic. Investigation on built case studies may lead to a better understanding of the efficiency of the smart urban furniture and their appreciation by the people.

4. Possible applications in Auckland

It has been demonstrated that, through smart technologies, Auckland's suburbia could transform to an energy contributor not only for its own transport needs but also to the city as a whole (Byrd, 2012). Auckland rooftop solar potential has been demonstrated also by a research carried out by the Energy Centre of the School of Business of the University of Auckland, Auckland Council and the Centre for eResearch (Suomalainen et al., 2017). A webtool (Energy Centre, 2017) has been developed after this research and it is available for the public. The user can select a building on the map by clicking on it and the annual solar radiation on the best spots on the roof will be given for 4 different areas. The tool is only focused on buildings' roof-tops, however it does not analyse open areas which are used for smart urban furniture. It should be noted that in a city like Auckland, only a few open areas of the CBD could host smart urban furniture, because of urban density and the presence of tall buildings overshadowing each other. In the CBD these tools can be useful to help homeless people to recharge their phones and offer access to free Wi-Fi. Energy generation can be useful also for providing temporary heating during winter.

In suburban areas more extended projects could be pursued: smart bus stops can be used for providing useful information to locals and tourists; smart street lighting can be helpful to prevent delinquency in the most problematic neighbourhoods. In addition, Tāmaki iwi are interested in solar community projects and specific programmes can be pursued with them.

There is a great need of research to understand what is the smart urban furniture that could be applied in the different areas of such a big city like Auckland. This research is at an initial stage and it is aimed at extending the knowledge on smart urban furniture and at understanding their potential application at our latitudes, also through experimental prototypes or pilot projects that can be funded by private or public institutions. A research proposal recently funded by the University of Auckland will investigate these aspects and develop a co-creative project.

5. Conclusions

This research focused on “smart” solar urban furniture, thus on urban furniture implementing solar technologies. A growing interest on this topic is demonstrated by several projects and real-world applications, with an increasing number of patents. The research identified 7 types of solar urban furniture: canopies, pergolas, carports, bus stops, benches, solar trees and street lighting; in addition, a number of experimental objects have been found present innovative solutions for the next future. More than 80 case studies have been investigated according to the criteria “architectural integration”, “context sensitivity” and “system visibility”. A selection of case studies has been described in this paper. Aims and potentials of solar urban furniture have been introduced as well as a number of limits that emerged from the case study preliminary analysis. The research highlighted the possibility of Auckland of hosting different types of projects of solar urban furniture, according to the expected goals and the features of the built environment. While Auckland CBD could host small projects in open areas such as public parks, the suburbs could host a distributed network of different tools. This research could be important also in conjunction with other strategic contributions to minimize energy loss in the energy distribution though the development of smart grids (Passey et al., 2011). In NZ, research projects on smart grids are being carried out by several institutions (Nair et al., 2015). Further steps of this research will involve: a more extended literature review, analysis of governmental policies, the study of possible prototypes, pilot experimental projects involving also Tāmaki iwi.

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