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Living with the sun: using canopy structures in Mexico and the UK

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Abstract

"Sometime too hot the eye of heaven shines"- especially in Mexico - "and often is his gold complexion dimmed" - especially in the UK. Meeting these challenges becomes ever more urgent as we burn fossil fuels into which the sun poured his energy long ago, thereby changing our climate - and meanwhile our population expands (Shakespeare [1]).
To explore how fabric membranes may help to meet these very different challenges, two tensile membrane structures have been studied, one in Mexico and one in the UK, with their very different temperatures, humidity and, above all, solar radiation.

This study analyses these two different architectural approaches in two different climates from the users´ point of view, especially their perceptions of thermal and luminous comfort during winter and spring seasons. The research follows a post-occupancy evaluation methodology designing and distributing a questionnaire for visitors and employees.
The first membrane structure is at a retail space, **Palmas Plaza**, in Puebla, Mexico (19º N). It features a six-coned canopy structure covering 6000 m^2, houses restaurants as well as shops. The fabric membrane structure was designed and built by SM Ingeniería y Diseño in 2004-05.
The second membrane structure is at a retail space in **Rotherham**, UK (53º N). A 900 year old market place whose existing building dates back to the 1750's, posed the challenge of installing a roof lay in creating minimal intrusion and impact on the existing structure. As a result, the roof was designed to be supported on six free standing masts, entirely independent of the existing buildings. The canopy structure was designed by Architen Landrell [2]. Both structures are used all year round: their environmental performance at different seasons is thus important to the users, and affects their perceptions. Hence, this study will, in the future, explore users' environmental perceptions of the case study buildings during Summer time.
Galileo [3] said that the sun, with all those planets depending on it, still finds time to ripen a bunch of grapes. Inspired by this happy thought, we have also looked at the forward-looking **Alpine House in Kew Gardens** designed by Wilkinson Eyre [4]. Here the need is for movable membranes that can provide sun and shade as the seasons, conditions and the

plants' needs vary.
It was found from the users' perception of Palmas Plaza and Rotherham market that the membrane structures perform well in terms of luminous comfort and ventilation but not so well for thermal comfort, aesthetics or functionality. The Alpine House seems to perform well in all environmental factors and aesthetics of the movable membranes (Table 1).

The potential of canopy structures to generate green energy through the exposure to solar radiation is also discussed: new materials and technologies allow harnessing energy from the available solar exposed surface. It was found that they can generate up to 534 MWh/yr in Mexico and 156 MWh/yr in the UK.

Table 1: General users´ perception towards the fabric membrane structures of the case study buildings.

BUILDING	Thermal comfort	Luminous comfort	Ventilation	Aesthetics	Functionality
Palmas Plaza	**X**	**OK**	**OK**	**OK**	**X**
Rotherham Market	**OK**	**OK**	**OK**	**X**	**X**
Alpine House	**OK**	**OK**	**OK**	**OK**	**OK**

Keywords: environmental performance, post-occupancy evaluation, thermal and luminous comfort, users' environmental perception, fabric canopy structures, thin film solar cell, green energy.

1. Introduction

The first membrane structure studied corresponds to Palmas Plaza in Puebla, Mexico (Figure 1). This canopy structure covers the roof a shopping centre with a total surface of 6,000 m^2. The PVC fabric membrane coated with Tedlar® PVF, houses a food court underneath. The shopping centre forms a lineal composition in an east-west axis and features two PVC fabric membranes: a six-coned canopy and an additional 'seagull' canopy [5].

Figure 1 (left): Palmas Plaza, Mexico (photo: SM Ingeniería y Diseño). **Figure 2 (right):** Rotherham Market, UK (photo: Architen Landrell).

Typical weather in Puebla, Mexico is temperate-dry with a minimum average annual temperature of 11.2 ºC and a maximum average annual temperature of 26.1 ºC [6]. The mean annual solar radiation available is 1,842 kWh/m^2 [7].

The second membrane structure studied corresponds to Rotherham Market in the UK (Figure 2). Covering over 3,500 m^2 of market, which was previously open-aired, the PTFE fabric membrane is located on the second floor for an existing complex built during the 1750s. This contrast between old and new, classic and modern is what makes the structure so intrinsically striking.

The 900 year old market place plays host to its market 6 days a week and numerous seasonal occasions as well. The unpredictable British weather meant that the need to protect the visitors was important, and the previously uncovered space was putting off potential visitors.

With the old existing structure still in place, the challenge of installing a roof lay in creating minimal intrusion and impact on the existing structure. As a result, the roof was designed to be supported on six free standing masts, entirely independent of the existing buildings [2].

Typical weather in Rotherham, UK is cold-humid with a minimum average annual temperature of 5.2 ºC and a maximum average annual temperature of 13.4 ºC [8]. The mean annual solar radiation available is 921 kWh/m^2 [7] - half of the radiation in Mexico.

The third fabric membrane studied corresponds to the Alpine House (Figure 3). The new Alpine House in the Royal Botanic Gardens at Kew, near London, applies great ingenuity to the problems of growing close to sea level a collection of plants whose natural habitat is the high mountains. The requirements were for plenty of light, but cool conditions, and steady movement of air. This has been achieved by a combination of moveable membranes for shade when the sun would be too hot, and air cooled by passing naturally through a labyrinth laid out within a double concrete slab in the earth below the house.


Figure 3: Alpine House, summer and winter (photos: R. Baker, 2009)

2. Methodology

The methodology followed, especially for the retail structures, is based on a qualitative research model through a user´s survey. A questionnaire was distributed among users and staff of the case study buildings. The questionnaire was designed to ask the users their environmental perceptions of the place at the time of their visit. By following this method it is possible to get the users' unconscious perceptions. The questionnaire is divided into three

sections: general information (age range, frequency of visits to the building), environmental perception and general perception towards the architectural solution of the buildings. The data was then processed using the statistical software SPSS v.16, results are presented in the section below. The population surveyed at Palmas Plaza in Puebla represents 14% of a regular weekend day, Sunday, which is one the busiest days. In addition, the shopping centre manager was interviewed about the impressions of their clients in respect to the roof cover and the implications for business incomes.

For the case of Rotherham Market, a representative although small population sample was interviewed, which can give us an overall impression of people's perception towards the market fabric structure. The market manager was also interviewed about the perceptions of both the market stall owners and the users' environmental perceptions.

Regarding the Alpine House, Kew Gardens did not feel able to bend their regulations enough for us to question visitors on the spot. Instead questionnaires were distributed to small number of people living locally who had visited the Alpine House regularly since it opened three years ago.

3. Results and Discussion

3.1 Palmas Plaza, Puebla, Mexico.

Users of Palmas Plaza Shopping Centre answered a total of 71 questionnaires. 49% of respondents are clients and 51% are members of staff, mainly waitresses, cleaning staff and vendors. Most of the clients (13 people) visit the building once per month followed by people who visit it once a week; hence they are familiar with the atmosphere inside the shopping centre (figure 4). The age range of 75% of respondents varied between 21 and 60 years old; 16% is less than 21 years old, while 9% is more than 60 years old.

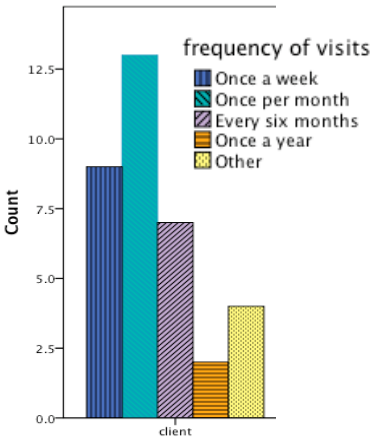

Figure 4: Clients´frequency of visits

People were asked to rate which environmental factor is more important when designing a retail building. Staff members rated lighting as the most important factor (38%) followed by ventilation and visual relationship between interior and exterior (31% each). Clients rated equally as the most important environmental factors lighting and ventilation (34%). May be the staff answer regarding the importance of having a visual relationship between the interior of the building and the exterior is relevant since they spend long working hours inside the shopping centre, and having outside views gives them comfort (figure 5).

Figure 6 shows users perception regarding the importance of the fabric membrane structure for the environmental performance of the building. There is practically no difference

between clients and staff responses, almost 80% of them think the membrane structure is important or influences the environment inside the shopping centre.

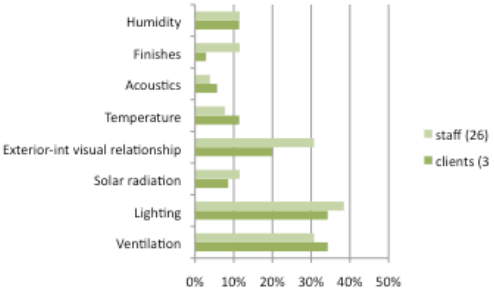

Figure 5: most important environmental factor.

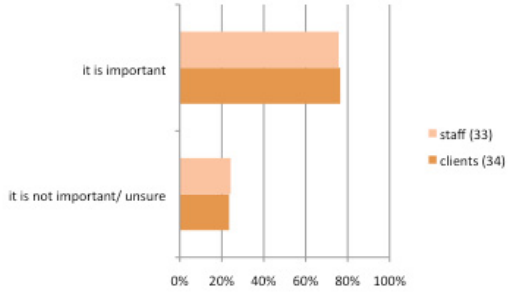

Figure 6: importance of the fabric.

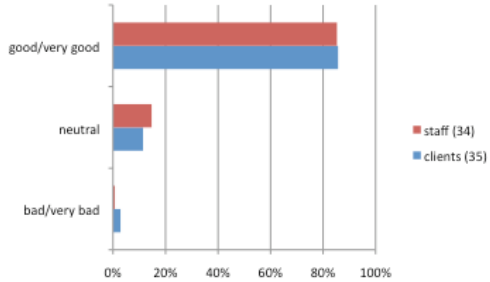

Figure 7: perception of daylight availability.

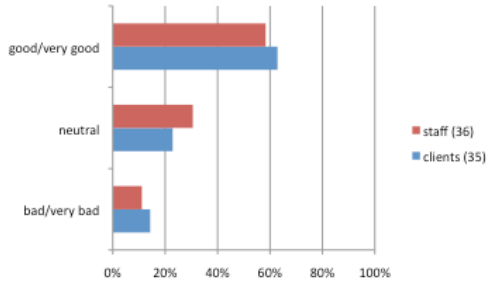

Figure 8: perception of artificial lighting.

Users believe daylight availability in the shopping centre is mainly good and very good (86% of clients and 85% of staff members); while only a few clients think it is bad. On the other hand, a higher percent of people believe that artificial lighting is bad/very bad and neutral; although the majority of respondents still think it is good/very good (63% of clients and 58% of staff).

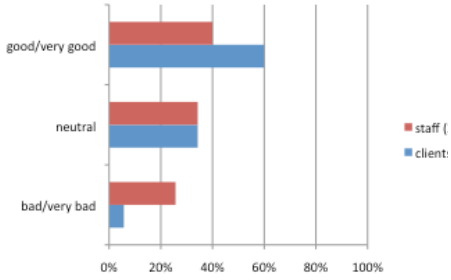

Figure 9: Acoustics perception

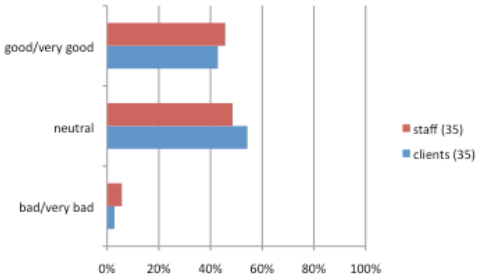

Figure 10: Temperature

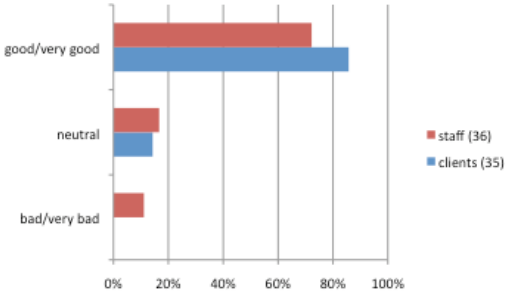

Figure 11: Ventilation perception

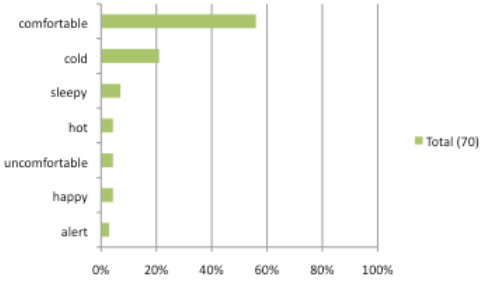

Figure 12: People´s mood inside Palmas Plaza

Acoustics in Palmas Plaza is, according to users, mainly good/very good; however there is a considerable amount of people who selected neutral may be because they never have thought about it before. Moreover, 26% of staff said acoustics are bad/very bad (figure 9).

Regarding temperature perception in the building, in general people selected neutral (around half of respondents), while other half selected good/very good. There is almost no difference between staff and clients answers (figure 10). It seems important to point out that the questionnaire was distributed in spring 2009. Nevertheless, the manager of Palmas Plaza in an interview held in February 2009 explained that the number of visitors considerably decreases during the winter months (November-February) because the shopping centre feels cold and gloomy. According to the manager, this kind of roof (fabric membrane structure) in a weather like Puebla, warm during the day but chilly at night, was not successful in terms of users' thermal comfort. As the food court is also used at night for

restaurants and bars, the visitors complained of the cold and draughty conditions and often it is necessary to use exterior gas heaters.

Figure 11 illustrates users perception towards ventilation in Palmas Plaza. Most of respondents said ventilation is good and very good (staff: 72%, clients: 86%). Users were asked about their mood when they are in the building, most of them selected comfortable (56%) followed by cold (21%) (figure 12).

In addition, users believe the fabric membrane structure directly influences the aesthetics of the building (80% from the total of respondents). They explained that the canopy structure is innovative with a strong visual effect; it is an elegant and modern structure that gives the shopping centre a unique image. Nonetheless, some people pointed out that the fabric structure looked attractive when it was new and clean, and now it looks dull because of dirt on the fabric and the lack of suitable lamps that could make the structure an icon at night. Others said that visitors stop coming to Palmas Plaza if it is raining or cold because the building is not airtight.


Figures 13, 14, 15: Exterior and interior views of Palmas Plaza (photos: J. Mundo, 2008).

3.2 Rotherham Market, Rotherham, United Kingdom.

Currently the open covered market in Rotherham operates Mondays, Fridays and Saturdays offering a variety of fresh products and goods. On Tuesdays the market displays second hand clothes and shoes and a busy atmosphere is created on Wednesdays by antique and Bric-a-Brac trade [8]. In 1996 as part of a town regeneration plan, Rotherham Metropolitan Borough Council put forward an idea to shelter the originally open aired market. The latter had a twofold intention to make more pleasant the visit of the buyers, considering the rainy and unpredictable British weather, and also to reinvent the image of the market. The proposed roof structure was commissioned to Architen Landrell who undertook responsibility for the design, engineering, manufacture and installation of the membrane structure (figure 16).



Figure 16 (left): Exterior view of Rotherham Market (Photo: Architen Landrell). **Figure 17 (centre)**: Free standing masts (Photo: M. Mendoza, 2009). **Figure 18 (right):** Flanking membrane elements flying over the existing building (Photo: M. Mendoza, 2009).

One of the main remarks within the regeneration scheme was to undergo the construction and installation of the structure without disrupting any of the trade activities in the market. Architen Landrell decided to minimize their activities' impact at ground level by proposing a structure fully supported on 6 free standing masts (figure 17) on an area of 3,500 sqm to support two conical membranes flanked by a series of bat wing shape-like membrane elements (figure 18). An interesting contrast between the traditional character of the 1750's existing building [2] and the new roof structure became an important visual element to reinvent the image of the market which had been badly deteriorated by the pass of time, poor maintenance and vandalism.

Figure 19: View of the market stalls (photo: M. Mendoza, 2009).

The designed shape and height of the structure also contributes to the stack effect enhancing the natural ventilation and thermal control of the market especially during hot summer days. The natural lighting design strategy called for a material with light transmittance properties and it was decided to use Poly Tetra Fluoro Ethylene (PTFE-solid). A visit to the site revealed that, most probably, due to low maintenance, accumulation of dust and other particles have adhered to the membrane thus decreasing the lighting transmittance performance of the fabric. In addition, the use of conventional market tents by the vendors has also resulted in a decrease of incident daylight at trade level around the market (figure 19).

Vendors/visitors/staff perception study

An overall representative sample of interviews to the staff, visitors and vendors were carried out in order to assess the user's environmental perception. In these interviews and questionnaires, vendors, visitors and staff management expressed that, mainly in winter, the space under the tent is rather cold and lacks of sufficient daylight. However, most of them also expressed that during the summer time, lighting conditions are better and also natural

ventilation alleviates any accumulation of heat in hot days. Interestingly most staff and vendors agreed that the structure has a higher functional value over an aesthetic one. In addition most young visitors (younger than 21 years old) didn't find the structure beautiful or innovative but rather boring and gloomy. However most of the middle and adult age interviewed people agreed that the membrane structure constitutes an iconic figure in Rotherham and that since its installation the number of visitors have increased as well as the sales enhancing the market's life in Rotherham.

3.3 Alpine House Environmental Strategy

The Alpine House environmental strategy is based on drawing cool air from underground in order to keep a cool environment for the plants. Together with a deployable fabric membrane to shade the sun, they make an effective combination of passive and active strategies. The underground labyrinth is based on the form of the interior of termites' nests. The large surface area cools down at night, and can act as a heat sink during the day. It cools down the air that passes through the labyrinth and is drawn up passively into the house (Figure 20) as hotter air escapes upwards and out through the stack effect – as in a chimney stack. The cool air arrives at the plants through a series of pipe nozzles that can be directed where cooling is most needed.

Figure 20: Fresh air is drawn up passively to the interior of the Alpine House (photos: R. Baker, 2009).

The notable height of the building is useful in two ways: it contributes importantly to the stack effect, and it provides the space required for the deployment of the moveable membrane screens when shade is needed (Figure 21). The Alpine house is oriented with its long axis running North-South. When not deployed the screens are housed in two troughs that run along the length of the East and West sides (Figure 22). When, for example, shade is needed from the afternoon sun in the West, the central hub on that side draws up two fan-shaped sets of membranes, one from either end, till they meet in the middle, when they resemble the tail of a peacock (on which they are based). Enough light filters through for visitors to enjoy the plants, and there is enough shading effect for them and the plants to be kept cool.

Some of the staff who looks after the alpine plants were involved in the design process from the start, and they are very content with the result, as indeed the plants seem to be. Visitors' reactions to the building were more affected by their views on the overall architecture of the building than by the deployable membrane structure. Indeed some had not seen it deployed, and even when it is fully open on one side it is still a much less prominent part of the overall architecture than a membrane roof in a retail space. The deployable membranes are nevertheless an essential part of the design, and there was general agreement among visitors that they seemed to be doing their job effectively, as is confirmed by the staff. The effect on the temperature as the membranes are deployed is felt immediately.

Figure 21: Height contributes to the stack effect of the Alpine House (R. Baker, 2009).

Figure 22: Deployable screens shade the interior of the Alpine House (photos: R. Baker).

3.4. Fabric membranes' potential to generate green energy.

The potential to generate green energy from the available exposed surface of fabric membrane structures is an important possibility to look at. New materials embed a single-ply roofing membrane with a thin film solar cell into the fabric material (Figure 23). Photovoltaic film made of amorphous silicon is directly laminated onto an ETFE membrane creating a translucent roof. We multiply the benefits of the environmental performance of a fabric membrane structure by adding the possibility of generating energy from a clean and free source like the sun. All or part of the exposed surface can be made with a thin film PV laminated into the membrane, offering free energy throughout the year.

Figure 23: Thin film solar cell embedded onto a roofing membrane.

A simulation of the available energy from the solar exposed area of Palmas Plaza and Rotherham Market fabric membranes was done using PVSYST 4.3 software. In order to quantify the amount of available energy of such surfaces from their different latitudes (Mexico and UK) an available area of 6,000 m^2 and 3,500 m^2 respectively, was simulated. Thin film amorphous silicon solar cell material was assumed with an efficiency of 4-8%. These types of cells are less sensitive to the angle of solar radiation and providing that the tensile membrane structures feature a surface with varying angles, it seems to be the perfect choice of photovoltaic material.

The amount of available electric energy output from Palmas Plaza membrane is of **534 MWh/yr** saving some **230 tons of CO_2**. On the other hand, the membrane from Rotherham Market could produce up to **156 MWh/yr** and save **67 tons of CO_2** emissions released to the atmosphere. This could also apply for the Alpine House case, receiving solar radiation when is deployed either in the morning or afternoon. This would generate some energy while shading the interior of the building at the same time.

Combinatorial approaches for fabric membrane structures which merge high-tech and low-tech solutions, would contribute in two ways: by reducing the energy reliance of the building on fossil fuels and by providing clean and free electricity. This makes indeed, a great contribution to the environment.

4. Conclusions

This research aimed to study users environmental perception in three buildings located in two different climates and countries: Mexico and the UK. Two of those buildings are retail spaces while the third one is a plants house in Kew Gardens, UK. According to users of the case study buildings, the three architectural solutions provide a dramatic effect that makes the buildings iconic figures within their built environment. One solution, the Alpine House, responds to seasonal changes in order to protect the plants. The other two buildings, which are designed for humans, provide weather protection and are not deployable or adaptable to different climatic conditions. Though all three fabric membrane structures were chosen for these buildings due to their ability to cover long-span areas with no intermediate supports.

In Palmas Plaza, users pointed out that the fabric membrane roof is a good solution for providing daylight but it is rather cold especially in the areas where people stay long time such as restaurants and cafes. They also said the building in winter is not comfortable due

to wind draughts and in summer the problem is rain because the membranes are not completely sealed to the rest of the building.

In the analysis of Rotherham Market it is important to consider that the environmental perception study is based on a rather small sample and therefore the research team is looking to study a larger sample of interviews and questionnaires before drawing definite conclusions. However, the study is representative and illustrates, overall, the users' perception and opinion of the sheltered space and the structure itself. In addition, the interviews have made the users aware of such environmental perception studies and their importance in regards with the users well being.

The Alpine House is a striking, even flamboyant, building. While some visitors may interpret this - and for instance its height - as architectural showing-off, the staff are in no doubt that it is fact very well designed for its purpose, and the form follows the function. It certainly seems to us to mediate very effectively between the varying conditions, e.g. of the sunlight, and the needs of the plants, and indeed of the visitors. That effectiveness seems to flow directly from the ingenuity of the design, and innovations that, in one way or another, make clever use of the warmth and light of the sun. These are, in particular, the underground labyrinth that provides a green supply of cool air, the height, which creates the stack effect that passively draws that cool air up to ventilate the plants, and the easily deployable peacock-tail membranes that give the plants the right mixture of sun and shade, and minimise their need for artificial light. Taken together, this makes for low energy running. As mankind wrestles with the climatic effects that flow from our suddenly releasing the energy of ancient sunlight stored in fossil fuels, there may well be more and more need for ingenious solutions of just this kind.

The computer simulation with PVSYST has shown the possibilities of integrating PV systems into fabric membrane structures, generating electricity while providing sunshade, clearly reducing some of the CO_2 emissions produced by our highly environmentally expensive life style.

As a general conclusion, it is possible to see the advantages that fabric membrane structures offer in terms of environmental performance, aesthetics, functionality, minimum use of materials and even energy generation. However, it is essential to consider also the climate and the function of the building and the membrane structure itself. This is relevant if designers want to create comfortable and energy efficient buildings taking advantage of new technologies and materials.

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