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Moving away from flat solar panels to PVtrees: exploring ideas and people's perceptions

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Abstract

Photovoltaic Trees (PVTrees) are artificial solar structures that look like sculptural trees and exist from small scale (size of a bonsai tree) to large scale (about the size of a wind turbine). The aesthetics of solar trees differ and they have been designed to provide different means of power to different urban and built environments. These range from powering mobile phones, electric cars, buildings and street lights covering small and large scale areas (one or a forest of PVTrees). This study brought together a research team of physicists and designers and to conduct focus groups with design based methods and prototyping (clustering of ideas, sketching and modelling) along with a computational 3D PVTree design tool. The focus groups consisted of capturing a) people's perception on PVTrees, idea generations and development of the 3D model and b) further discussion and evaluation of insights. A public exhibition followed to capture public perception on design concepts using 3D models, and a voting exercise. Overall it was found that PVTrees were received positively by the public with desires for them to be multifunctional by providing power yet also having a secondary function e.g. a shelter or seat. The paper details this, considerations for concept development, and the future direction of research in the area.

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Keywords: PVTree, Public perception, 3D model, focus groups

1. Introduction

Climate change is a major global issue with public concerns around the topic growing. According the IPCC (Intergovernmental Panel of Climate Change) C02 emissions have risen [1] and are going to increase further in the

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next decades as consumption of fossil fuels for heating, transportation and general energy usage is growing. The UK has committed, according to the Climate Change Act 2008 [2], to reduce its greenhouse gas emissions to at least 80 per cent lower than the 1990 baseline by 2050.

The UK Government has been working on the design and delivery of an ambitious new set of policies [4]. The Green Deal boosts action by households and businesses in energy efficiency measures. This, together with the roll out of smart meters, and other energy efficiency policies to support industry and businesses, may create the conditions for the domestic and non-domestic sectors of the UK economy to deliver challenging but achievable emissions reductions. In addition to more efficient energy usage behaviours by people, renewable energy sources are fundamental to achieving this.

1.1 Photovoltaics (PVs) as electricity sources

The UK Government estimates that 20.1 TWh of renewable heat was generated in the UK in 2013, or about 2.8% of heat demand, with the proportion increasing from 2006 to 2012 after steady decline from 1994. As of June 2013 the UK has 2.4GW installed capacity generating 1.4TWh of electrical energy. The UK government is committed to substantially increasing the deployment of renewable energy across the UK and recognises the potential ro le and contribution that solar energy can play in helping to meet targets of 15 per cent renewable energy 2020. The extensive deployment of solar technology across the UK has become increasingly visible to the public at all scales and is among the most popular renewable energy technologies. Recently solar received the highest public approval rating of all renewable energy technologies at 85% [4].

Solar panel electricity systems, also known as solar photovoltaics (PV), capture light energy using photovoltaic cells. These cells do not need direct sun light to work and operate in a variety of light levels [3]. The cells convert the light into electricity for a wide variety of applications[3] . PV cells are made from layers of semi-conducting material, usually silicon. Through capturing light on the cell it creates an electric field across the layers with light intensity corresponding to an increase in energy production. Groups of cells are mounted together in panels or modules that can be located in a variety of sites.

Innovation is key to improving performance and efficiency of PV panels in order to bring down the cost of production [4]. PV technologies have developed significantly over time, and different technologies are at different states of maturity. First generation technologies, such as crystalline silicon, dominate the market with their low costs and commercially viable efficiency [4]. Second generation technologies, which use thin films to reduce high manufacturing and materials costs, are similarly reaching maturity.

Research and development activity in place for a range of PV technologies and applications, which are predominately focused on academic research of next generation technologies [4]. The integration of physics modelling and engineering is required to create advances in the field. Indeed, physics based modeling has been shown valuable for mathematical description of solar cells and improvement in efficiency. Most research efforts are towards improvement of laboratory cells. In the specific case of thin film PV, the solar power conversion efficiency has been improved [5]. Yet although mathematical modelling may optimize PV panels for efficiency the public perception of them may go some way to determine their ultimate success. Indeed, Connor et al [6]acknowledge other barriers including public perception issues particularly noting that solar technologies can be seen as complicated, unproven and of dubious benefit by the general public [6]. Indeed, despite the objective of solar panels (and plants) being the generation of "clean" energy these technologies induce a visual impact of given magnitude which affects the emotional state of the viewer [7]. This loss of affection towards the landscape [7]may therefore turn people away from this valuable source of renewable energy.

Due to this variability in public perception more novel structures balancing efficiency and public acceptability may be needed. Solar trees may be one such novel concept. These are structures utilising PV panels as 'leaves' with which to capture light. Importantly, they can be novel in shape as they are can be bespoke platforms with which to position PV panels. Since the angle of sun rays vary particularly during the changes in seasons, solar panels fixed to roofs for example may not be fully optimized. Some residential solar systems are designed to move and track the Sun but these systems substantially increase the cost of solar energy because they are expensive and require maintenance[8].

Therefore one potential solution is by using natural structure forms (such as the shape of trees) and the advancement in PV technology to better optimise solar structures (see Avdic et al [10]). Furthermore, because solar panels are transformed from being positioned as horizontal panels, the opportunity for creating a more pleasing aesthetic for public places arises. However, there has been limited public involvement in the creation of pleasing shapes that may also be optimized for solar energy capture. The aim of the presented study was to understand public perception to the solar tree concept and to elicit design input to feed into an optimized mathematical model of efficiency. This paper reports on the collection of public perceptions and discusses this in terms of implications for structural shapes and the direction of future work in the area.

2. Methodology

The research team conducting this research were from Physics and Design, which allowed design directions to be explored at the same time as optimizing the design mathematically. In order to explore public perception on the design of solar trees two focus groups were held with members of the public and university staff. Using physical provocations (3D modeling, location maps, drawings, clay modelling, clustering of images and annotation) to elicit discussion and debate, the concept was explored.

The study involved a three stage process (fig. 1). The first two parts involved focus groups to gather insights into the initial concept and then refine ideas. Based on these triangulated results four concept designs were produced as both a CAD model and 3D printed models (figure xx). Models were then displayed as a small public exhibition to allow a broader sample of university members to assess the concepts and complete a short questionnaire.

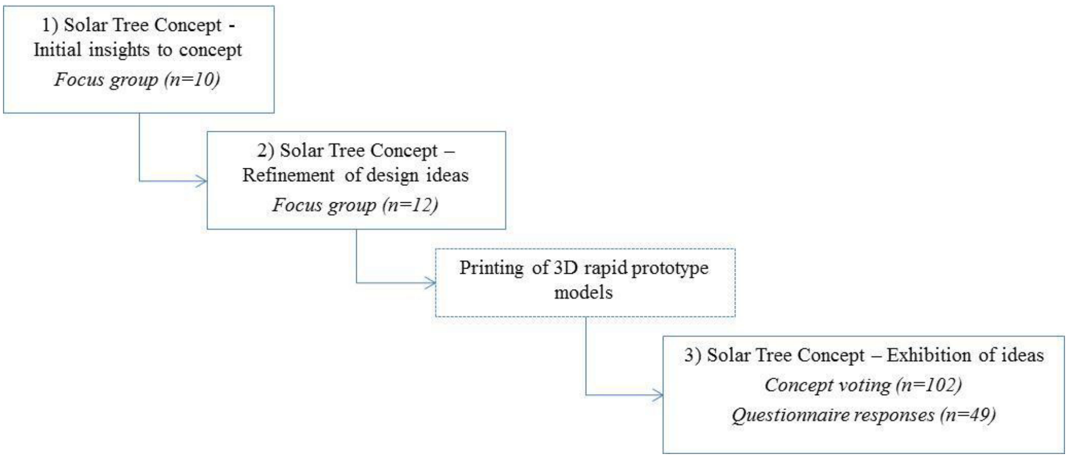

Fig. 1. Study process.

2.1 Sample

The focus group sample consisted of 16 participants drawn from University staff, students with one external architect. Eight of the participants took part in focus group 1 and 2. Modal age was 34 years with 11 male and 6 female. A total of n=102 respondents from the University community voted on the concept of solar trees during the exhibition. Of these n=49 participants voluntarily completed the feedback questionnaire (n=19 male, n=20 female and n=9 did not provide this information).

2.2 Focus group procedure

The two focus groups used the same broad framework of topics (understanding of the concept, ideal location and 3D modelling of ideas) to maintain consistency between sessions but differed in the specific tasks reflecting iterative process of the study. Both were held in the same seminar room over a morning period lasting 2 hours. A four week period separated each. Focus groups were audio recorded for analysis with researchers ED, JM and GJ facilitating the session and making observational notes about pertinent comments and themes throughout.

Focus group 1 explored public perception of the built and natural environment on the University campus and used this as a setting location for the concept. Participants were asked to consider this and then develop their own design for a solar tree to fit in with the surrounding urban context. Specific tasks within focus group 1 were:

1. Introduction to project and session
2. *Gathering insights:* Participants completed a tree categorisation task consisting of a picture task where each participant clustered their favourite living trees in order of preference. Reasons for their choice were recorded.
3. *Gathering insights:* Presentation of a hypothetical solar tree (using interactive white board). Discuss on initial thoughts on concept.
4. *Idea development:* Developing prototypes. Participant's completed paper based tasks to design and build a solar tree concept (using paper, card modelling material). Annotations of the models recorded reasons for shape, colour form etc.

The second focus presented and developed the insights from focus group 1. The same activities were used with the addition of considering urban and non-urban locations and the potential effect this may have on public perception and subsequent design. Probes were used to support the discussion. Participants were divided in two groups of n=6 people for the round-table discussions. The discussion was supported using the most salient images and designs collected from focus group 1. Specific tasks within focus group 2 were:

1. *Gathering insights:* Feedback on current findings
2. *Gathering insights*: Tree categorisation task (repeated from focus group 1).
3. *Idea development:* Presentation of the higher fidelity (CAD images) solar tree concepts developed from focus group 1 in a contextual scenario. These were presented on interactive white board and paper.
4. *Idea development:* Group discussion about the acceptance and practicality of the concept of solar trees.
5. *Finalised ideas:* Developing final prototype concepts using modelling and drawing.

2.3 Exhibition

The exhibition was run over four days at three locations across the University campus. This consisted of four 3D printed solar tree models, voting boxes and questionnaires. Passersby were asked to vote on their favorite concept after a brief description of the project. If willing they were also encouraged to complete a short questionnaire asking why they had chosen their option and opinion on the concept.

2.4 Analysis

Data was analysed in an inductive manner – discovering patterns and themes [9 p. 453] which were used to understand the perception towards the concept of solar trees. Specifically content analysis was carried out looking at the low level manifest content and latent content [10 p. 354] . This refers to assessing the content of the responses during the focus groups (manifest content) and then using theory (from design and psychology) to infer deeper meaning in interpretation (latent content). The iterative process meant that the most salient themes of the data (e.g. particularly resonant shapes) were explored within at each stage of the project. This iterative process was used to create design recommendations to feed into the mathematical model of the tree structure (no reported here) in an effort to balance positive perception and efficiency.

3. Results and discussion

The focus groups proved successful in creating debate and ideation around the concepts of solar trees (figure 2). Indeed, for many, although PV cells and panels were understood, constructing them as new solar forms was a new and novel idea. The triangulated findings from each focus group revealed six key themes relating to; aesthetic, structure, function, PV panels, feelings and concerns.

Figure 2: Participant discussion using interactive white board.

3.1 Aesthetic, structure and function

Aesthetic referred predominantly to the colour of the tree. Options for bolder colours where discussed by participants and although preferred by some, natural elements were chosen as it was felt that these created cohesion with expectation and natural trees. This congruence with natural surroundings was a concept that continued. Indeed, this may have been expected as the biophilia hypothesis promotes the benefit of the association nature has for most individuals, be it through visual (or auditory) stimuli [11]. This postulates therefore, that although solar trees may be a technological concept, in order for public acceptance natural look may play a fundamental roll. Furthermore, this offers the potential to explore structure such as this in relation to human health and wellbeing as acceptability may create positive behaviours associated with technologies [12].

These natural elements were seen as a requirement for the structure and as well as green colouring, integration with planting was a positive concept through growing plants up the structure.The physical structure continued this theme with most participants (n=15) drawing ideas shaped like natural trees/plants. Tiered branches were preferred. This related to participants perception that this might create an optimal setting for the PV panels. As well as efficiency considerations such structures may have additional functions such as seating or shelter. Indeed, drawings and descriptions described the structures as a basic tree shape consisting of a trunk and branches. Relatively few had a large number of branches with most having broadly spread branches to support the larger leaves.

This combination of structure and function is seen in figure 3. A solar tree positioned within an urban space was perceived as a location for socializing during different seasons and formed an interactive and practical element of the environment in which could be located. Drawing on this use of the tree as charging points for small energy items (mobile phones, laptops) were particularly encouraged, along with the energy being stored for later use. Indeed, this falls under the network metaphor that Hidding and Teunissen (2002) promote in urban planning [13]. This is where elements of spatial planning supports integrated networks for transport, persons, information among others. As planning laws and regulation may govern the ultimate use of solar trees understanding how these structures may contribute and support to our future and existing social and physical networks is important. When composing an acceptance framework for sustainable technology Huijts et al (2012) makes reference that positive affect and perceived benefits are two sets of criteria[12]. If structures such as this might be of benefit to the 'integrated network' acceptability may results. These social and spatial implications may be an area for future work.

The perception as to the appropriateness of the concept is dependent on the surrounding environment (context), hence the location of such structures within urban and non-urban spaces was explored. Within urban spaces it was desired that these structures should be smaller than natural trees to resemble a more sculptural object. Conversely, if positioned in rural spaces size might be larger to increase optimization and reflect the larger scale of the surrounding environment. Although not explored in detail, these contextual factors will undoubtedly play a shaping role in the acceptability of this technology (see Huijts et al (2012) as personal factors play a role in acceptance – the 'not in my back yard' attitude towards wind farms is one example.

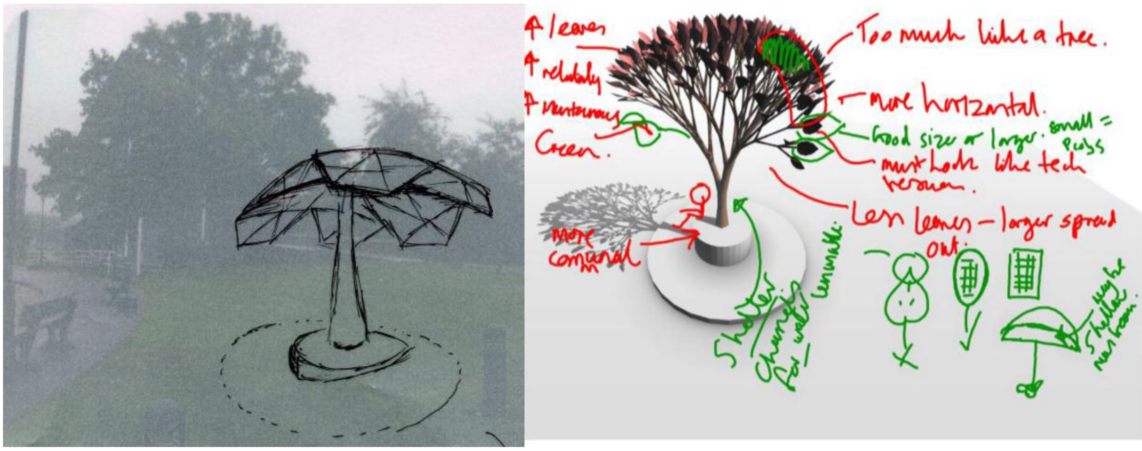

Figure. 3. . Sketches of Solar Tree concept from focus group 1 (left) and interactive board session during focus group 2 (right). *Note,* natural look and function of tree

3.2 PV panels

One point of discussion centered on the shape of the PV panels or 'leaves'. In the first focus group participants were given no bounds as to the practical limitations of PV panels or structures to enable preference for shape and form to emerge. Most wanted large 'leaves' to collect light and provide shelter. These were a natural 'leaf' shape rather than rectangular or other basic shape forms (as most existing PV panels are). There were comments that these shapes provided a more *"organic"* and softer aesthetic look – linking to the natural looks for these structures. Comments were echoed in focus group 2 with PV panels depicted as spherical in shape with participants remarking that this would capture a greater range of light (dispersed from other objects) and also this may improve the aesthetic of the panelling. Therefore, second generation development (see [5]) of PV panels may investigate more *"organic"* shape forms in an effort to move to a less uniform look. Ultimately, creating socially acceptable PV shapes and novel use of panelling may contribute to the uptake of solar energy technologies.

3.3 Subjective feelings and concerns

The latent content of the focus group captured the subjective response to the solar tree concept through participant language. Overall, the concept created positive feelings. Indeed, semantics used to describe this included *"welcoming", "calming"* and *"socially acceptable"*. Although these provide a snapshot insight into the feelings that these structures may evoke, capturing subjective response can be a useful planning tool when deciding on urban planning interventions (see soundscape work of Yang [14], Cain et al [15]). Therefore, designing these structures for positive subjective feeling may be a useful tool in the future. Linking this to PV panel development could help balance efficiency and acceptance for such technologies.

Concerns were raised around pragmatic issues. Optimisation was the main discussion point with the shadowing and the orientation of the PV panels noted as limiting ultimate efficiency. Likewise it was mentioned throughout by participants that the exact performance of the structure would contribute to determining the ultimate acceptability towards the concept of solar trees. This was an interesting point and supports Huijts et al's [12]view that knowledge about how such technologies work can influence people's perception of cost, risk, and benefits which indirectly contributes to decisions about the acceptability of the technology. This view was one that emerged further within the exhibition.

3.4 Broader perception: exhibition

The exhibition successfully attracted participants to vote on their tree structure preference and also complete the questionnaire available. The most preferred structure was model D (figure 4) obtaining n=42 (41.2%) vote. This was somewhat expected as this was the most natural looking structure that had been created based on insights from the focus groups. However, Model B received n=38 (37.3%) votes. This structure was the most distant from that of a natural looking tree structure. Therefore, we postulate that preference for this was based purely on aesthetic (relating to novelty) rather than based on a holistic understanding of the solar tree concept. Models A and C received n=4 (3.9%) and n=18 (17.6) votes respectively.

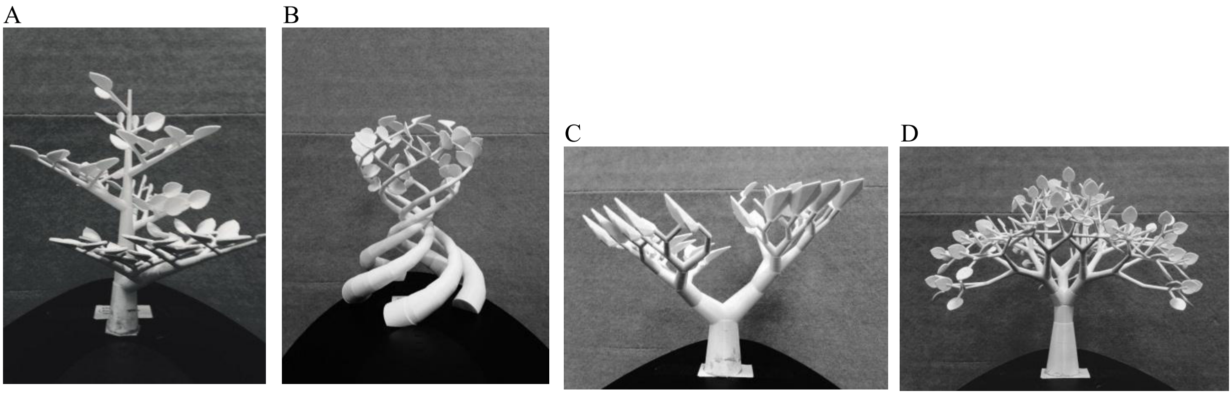

Fig. 4. Concept model (labelled model A – D left to right).

Feedback obtained from the questionnaire goes someway to explain these choices and concur with the themes developed within the focus group. As expected the tree preference of the questionnaire ratings mirrored those of the voting system with n=22 remarks commenting on the suitability of structures shaped as model D, with n=18 for model B. Reasons for choosing model D centered on the natural structure and therefore such structures may blend more easily into the environment in which it may be situated: "[it is] *able to merge with background"*. Preference for model B was that it looked more abstract and therefore resembled a type of art rather than an energy device: "*I like how it is abstract and looks a bit different"*. However, the overriding view from respondents was that knowledge about the efficiency of the tree, not just the aesthetic, was required for a true appraisal of the benefit of this type of technology:

- *“Is the shape of the trunk too big to be efficient?”*
- *“The problem would be the conversion efficiency from what I know. Efficiency needs to be improved to have potential.”*
- *“Energy produced per space taken up wouldn’t be as effective as wind farms.”*

Therefore, as was found in the focus groups, in order for the solar tree concept to be accepted as a legitimate form of energy technology and not seen as a ‘gimmick’ the efficiency of the structure required calculation and optimisation. Furthermore, such information should not be kept from public view. Displaying efficiency figures for this type of technology may provide meaningful feedback as to help increase public knowledge and help give acceptance to the idea. This may be particularly effective if given in relative values to other energy sources. Indeed as one additional comment reports “[the] *primary impact should be usefulness and sustainability not aesthetic!”*

4. Conclusions

This study has provided the preliminary investigation of the development of solar tree concepts in relations to public perception. On the whole participants were positive and encouraging towards the concept. Despite these structures being manufactured natural elements should play a fundamental role in terms of shape, colour and structural elements. It is therefore necessary to understand how these structures in urban spaces may be developed to provide a functional element of the environment and also utilize natural elements to potentially create positive subjective feelings that may influence health and wellbeing. Although efficiency is the key determinant for moving this concept forward (and is currently in progress as part of the presented work) the social acceptability is also important in order to create accepted sustainable energy technologies as integrated networks in urban spatial planning. Therefore, developing solar ‘trees’ requires a multidisciplinary outlook. Led by optimised efficiency (through use of computational modeling) aesthetic and function may be enhanced by drawing upon design, psychology and sociology theory. This outlook may provide an exciting and innovative way forward for solar technology development.

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