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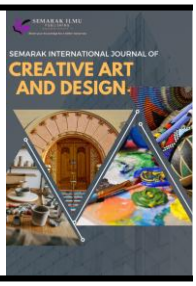

Dynamic Folding Envelope Design

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ABSTRACT

This study focuses on the development of the Dynamic Folding Envelope Design (DFED), a portable shading device created in response to global warming challenges. Addressing the need for environmentally conscious yet comfortable shading solutions in outdoor recreational spaces, particularly glamping, the research aims to create a user-cantered, versatile, and customizable device. Utilizing research tools, user testing, interviews, and prototyping, the study culminates in an Arduino-powered prototype. Survey results and in-depth interviews highlight the demand for features such as replaceable canopies and autonomous functionality, while also identifying practical hurdles like hardware limitations and coding complexities. The study reviews the DFED's practicality and efficacy, emphasizing the importance of addressing technical challenges and refining design aspects. Overall, the DFED represents a significant step towards sustainable and user-friendly shading solutions in outdoor recreational spaces.

1. Introduction

The project addresses the growing demand for efficient and ecologically friendly cooling solutions in outdoor environments. This program is motivated by worries about rising global temperatures and recent incidents of excessive heat, underlining the critical need to reduce discomfort in outdoor spaces.

Global warming, a phenomenon, has resulted in temperature increases, which have had a dramatic influence on nations all over the world. Countries like Singapore, Malaysia, and Brunei are struggling with the consequences of encountering difficulties that impede productivity and outdoor activities. The rising temperatures produced by global warming have forced people to seek shelter indoors, increasing the difficulties created by carbon emissions [1].

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1.1 Brunei Sports & Outdoor Culture

Brunei's rising and developing outdoor culture presents an intriguing picture of evolving leisure habits. Hiking, jogging, picnics, camping, and the burgeoning trend of glamping have all gained appeal in addition to traditional sports. This phenomenon also prompted renovations and even 'Add-ons' to existing recreational parks. Last year, a ceremony was conducted to commemorate the unveiling of multipurpose huts and facilities at Bukit Saeh Recreational Park [2]. This cultural shift is exacerbated by the increasing utilization and investment of outdoor facilities such as campgrounds, BBQ areas, and natural parks. These areas are more than just for enjoyment; they demonstrate society's proclivity to embrace nature and discover solace, inspiration, and peace which fuels the demand for sustainable outdoor infrastructure [3].

1.2 Dynamic Facades

Dynamic facades are innovative building skins that adapt to environmental changes [4]. enhancing indoor experiences and promoting sustainability. Unlike traditional designs, these facades respond dynamically to conditions such as solar radiation, daylight, and heat, creating a symbiotic relationship between the building and its environment. Key design features include adjustable louvers and shading systems for sun control, natural ventilation mechanisms to maintain air quality and harness wind energy, and the integration of solar panels and flexible thin films for energy generation. These features ensure thermal and visual comfort, reduce energy consumption, and align with the global shift towards renewable energy sources [4,5]

The integration of dynamic facades transforms architectural design by improving energy efficiency and economic value while meeting regulatory requirements and reducing energy demand. Designing these facades requires a comprehensive approach that considers financial, environmental, and socioeconomic factors. Their adaptive nature ensures energy efficiency and structural integrity, setting a new standard in sustainable architecture [5-6]. By balancing aesthetic appeal, environmental response, and technological integration, dynamic facades mark a significant advancement toward buildings that actively interact with their surroundings, benefiting both occupants and the planet.

1.3 Dynamic Facades: Case Studies

The Kiefer Technic Showroom is an example of how architecture and nature can coexist together. Its responsive facade not only reimagines building exteriors, but also establishes new standards for user engagement and environmental sustainability. This miracle exemplifies the boundless potential of inventive, environmentally friendly design [4,7].

The Al Bahr Towers are a model of dynamic façade engineering, harmoniously merging classic elegance with cutting-edge technology. Their adaptive Mashrabiya system not only improves the visual attractiveness of the towers, but it also demonstrates the power of adaptive design in decreasing energy consumption and boosting environmental sustainability [4,8]. The role of the towers as a beacon of innovation, setting new benchmarks in dynamic façade design and influencing future architectural undertakings, is highlighted in this case study.

1.4 Umbrellas

The umbrella, a timeless symbol of protection, has evolved from its ancient origins to become an essential tool in modern society. Tracing back to Mesopotamian societies as early as 5000 years ago, umbrellas were initially used by people of high social status to shield themselves from the sun [9]. Ancient China developed umbrellas from bamboo and animal leather around 3500 BCE, while Egypt's pharaohs used feathers and palm leaves for sun protection [10]. Over time, the umbrella journeyed through various cultures, including Rome and Greece, transforming from simple sunshades into versatile weather protection tools. This historical evolution highlights the umbrella's enduring cultural significance and human ingenuity in adapting to natural challenges.

Modern umbrellas are designed with functionality and durability in mind, featuring canopies made from materials like nylon and polyester that offer water resistance and UV protection. The metal shaft, often made of steel or aluminium, ensures structural stability and ease of use. Mechanisms for opening and closing the canopy, including manual and automatic systems, enhance usability, while wind-resistant designs add durability [10]. Umbrellas are effective in mitigating heat by blocking UV rays, with studies showing sun umbrellas can filter up to 99% of harmful solar radiation using UV protective materials while normal umbrellas provide significant UV protection at least 77% of UV radiation [11]. Widely used for sun protection, especially in Asia and the Middle East, umbrellas continue to provide comfort and safety against the elements, illustrating their ongoing relevance in a changing world. The widespread use of umbrellas as sun protection instruments highlights their importance in encouraging outdoor comfort and protecting against the harmful effects of UV radiation [12].

The increasing public interest in outdoor leisure and recreational activities, coupled with a preference for cooler environments, drives the demand for innovative cooling systems that enhance comfort. High temperatures and sun exposure often hinder the enjoyment of outdoor activities in locations like yards, parks, and public areas. To mitigate these challenges, there is growing interest in exploring various cooling systems that can be used individually, communally, or integrated into buildings. Developing such devices can improve comfort, well-being, and promote outdoor engagement, encouraging healthier, more active lifestyles. The project's design aims to create practical, affordable, and environmentally friendly cooling solutions to enhance outdoor comfort and participation in outdoor activities. While emphasizing the critical requirement for adaptive designs and long-term product development to reduce environmental effects [13].

2. Methodology
2.1 Research Analysis
2.1.1 Design inspirations

Direct inspiration towards the DFED design, to reiterate is as a dynamic tool that responds to weather conditions. Existing devices that cater to this problem other than dynamic facades are typically available which are in essence, normal umbrellas. The means of improving these products in terms of several aspects are vast. However, in the case of this project, it is mainly in its automatic means of opening and closing.

2.1.2 Incremental innovation & functionality

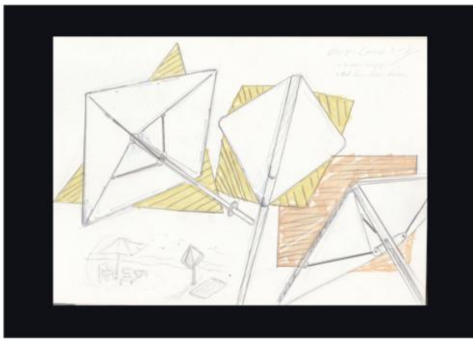
Design innovation in the Dynamic Folding Envelope Design (DFED) system is characterized by gradual advancements, especially in developing an automatic opening and closing mechanism. This incremental innovation involves continuous improvements, with each upgrade building on the existing framework [14]. As a result, the DFED has significantly advanced, and the addition of the automatic mechanism has greatly enhanced user experience by eliminating the need for manual operation. This focus on gradual innovation ensures that the DFED remains at the cutting edge of portable shading devices, adapting to meet user needs in outdoor environments.

In conclusion, the DFED system exemplifies the impact of incremental design innovation, particularly in the development of an autonomous opening and closing mechanism. This iterative process leads to minor but significant improvements, resulting in a more refined and user-friendly product. The DFED's incremental evolution underscores the necessity of ongoing improvement in achieving optimal performance and customer satisfaction [14].

2.1.3 Frame insight

A Frame Insight is a concise summary of key patterns and insights gleaned from the study of data. Data is sorted, clustered, and organized to find relevant patterns and trends that can be used to make decisions. Frame Insights provides a better understanding of study findings by reviewing contextual data and identifying recurring trends. These findings frequently result in the development of guidelines or principles that guide future inquiry and solution formulation in the research process. [15]. For this project, it covers prioritizing operational systems which is based on Medina Haram Piazza, which excelled in operational systems, this principle highlights the need to prioritize efficient and effective systems in design. Designers can ensure a more seamless implementation and user experience by emphasizing efficient processes and functional operations. Next, the project is emphasizing functional features which is drawing on the Outdoor Master Beach umbrella distinguishing attributes and usefulness, this notion highlights the necessity of prioritizing functional features in design. By focusing on factors that promote usability and practicality, designers can build products that better meet the demands and preferences of their customers. Considering usefulness and size also has been put into the criteria which mainly on the drawing on the Totes Eco Auto Open Umbrella, which stood out for its usefulness and overall size, this principle emphasizes the significance of striking a balance between functionality and size considerations. Designers should strive to produce designs that provide adequate space and utility while satisfying the practical needs of consumers, maintaining a harmonic balance of form and function.

2.2 Final Concept Sketches & Design Analysis
2.2.1 Final concept sketches


Final design sketch 1, using a generic umbrella opening mechanism

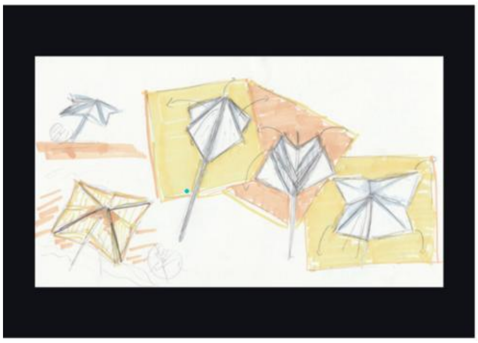

Final design sketch 2, using an inverted umbrella opening mechanism.

Fig. 1. Figure shows a 4-point canopy design

Figure 1 shows the final concept sketches for a 4-point canopy design.

2.2.2 PUGH design analysis

PUGH analysis, developed by Stuart Pugh, is a decision-making tool that systematically evaluates multiple design concepts against specified criteria, aiding in selecting the best solution based on weighted variables. In the Dynamic Folding Envelope Design (DFED) project, it assesses each concept's strengths and weaknesses, guiding the choice of the most promising design direction. The next section will present the PUGH analysis results, highlighting the preferred design concept and its advantages over alternatives. Table 1 shows the PUGH table for the project.

Table 1
PUGH table

Criteria	Importance	Design Option 1	Design Option 2	Control (Normal Umbrella)
Cost	1 (normal)	1 (worse)	-1 (worse)	1 (better)
Energy Efficiency	3 (extremely important)	0 (average)	0 (average)	0 (average)
Ease of Maintenance	1 (normal)	1 (worse)	-1 (worse)	1 (better)
User Experience	1 (normal)	1 (better)	1 (better)	0 (average)
Sustainability	1 (normal)	1 (better)	1 (better)	0 (average)
Adaptability	2 (very important)	1 (better)	1 (better)	0 (average)
Aesthetic Appeal	2 (very important)	0 (average)	1 (better)	0 (average)
	Total (=)	6	4	2

From the table above, it is apparent design option 1 (final sketch 1) performs better under PUGH analysis. Expressing a favoured direction towards the progression of the project.

2.2.3 SWOT analysis

The Dynamic Folding Envelope Design (DFED) offers strengths such as user-cantered design with its automatic mechanism for improved user experience and a focus on environmental sustainability with eco-friendly materials. However, it faces weaknesses like increased design complexity, affecting production and maintenance costs, and limited applicability to specific settings. Opportunities include tapping into the growing market for sustainable products and forming collaborations with outdoor brands to enhance market presence. Nonetheless, DFED faces threats from a competitive market requiring effective differentiation and rapid technological advancements necessitating continuous innovation. Figure 2 shows the SWOT chart for this project.

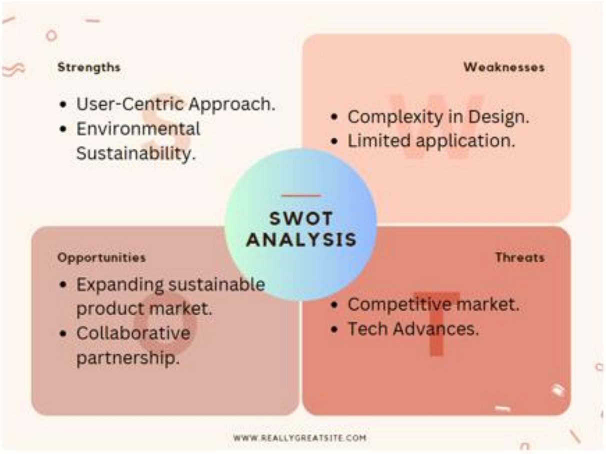


Fig. 2. SWOT chart

3. Results

3.1 3D Modelling and Refining

The final 3D modeling was presented in this section. Figures 3, 4, and 5 show the overall 3D model for the DFED Umbrella while Table 2 shows the part list.

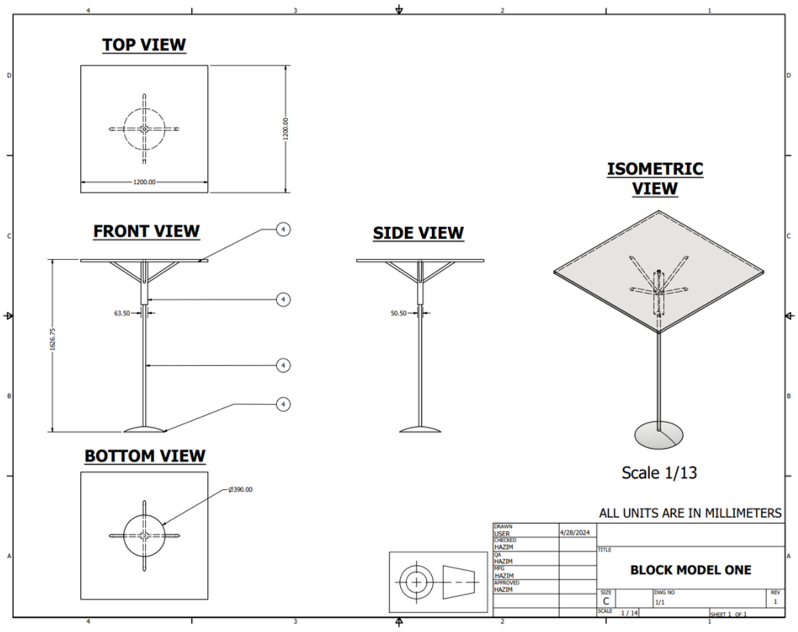


Fig. 3. Early technical drawing of the mock 3D modelling DFED Umbrella

Table 2
Parts list technical drawings of the mock 3D modelling DFED Umbrella

No.	Part List	Notes
1	Canopy	Dimensions taken from generic handheld umbrella.
2	Automatic Mechanism	Dimensions are derived from available components.
3	Post	Dimensions are taken from available posts from a domestic drying rack.
4	Base	Dimensions taken from existing poster holder.

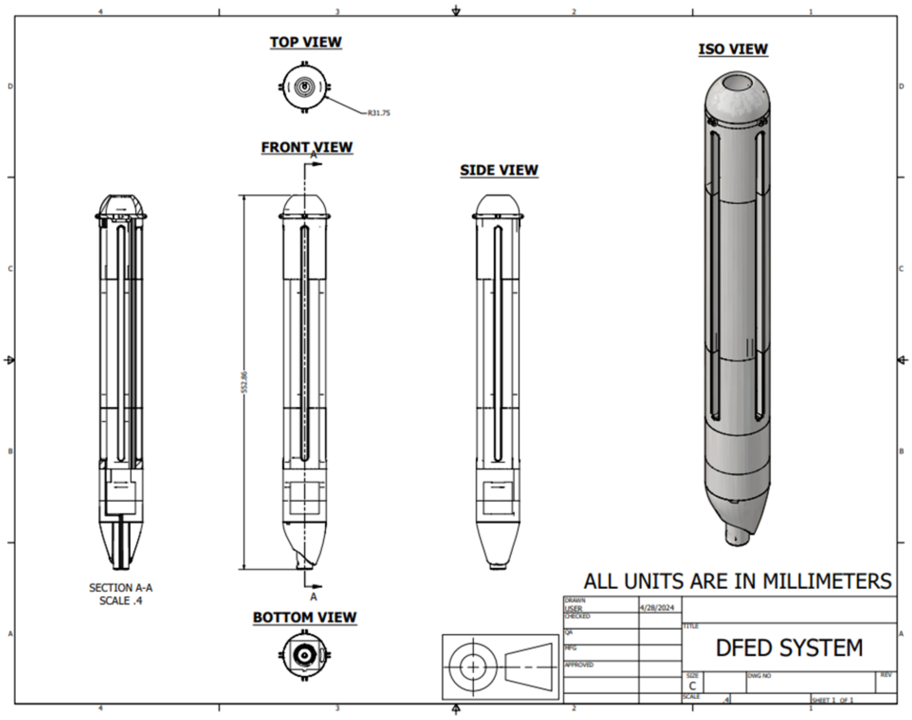


Fig. 4. Technical drawing: improved DFED system enclosure design

(a) (b)

Fig. 5. Figure shows (a) An isometric perspective view of the final design assembly without trusses and (b) A context use of a final design rendering put into a real environment using Augmented reality technology and image editing

3.2 Block Model & Arduino Prototyping

The design incorporated the Arduino system as shown in Figures 6 and 7. The DFED (Dynamic Folding Envelope Design) is an intelligent, auto-reactive device designed to open and close its canopy based on its environmental surroundings. The system responds to changes in light intensity and temperature. When the sensors detect an increase in light and heat beyond a certain threshold, the Arduino controller triggers the stepper motor to rotate. This rotation adjusts the canopy, either opening it to provide shade or closing it when conditions are cooler and darker. If the sensors do not detect sufficient light and heat, the canopy will automatically close.

(a) (b)

Fig. 6. Figure displays (a) side-view DFED system without the canopy and trusses in closed position (b) the underside the canopy view of the DFED system with exposed wiring

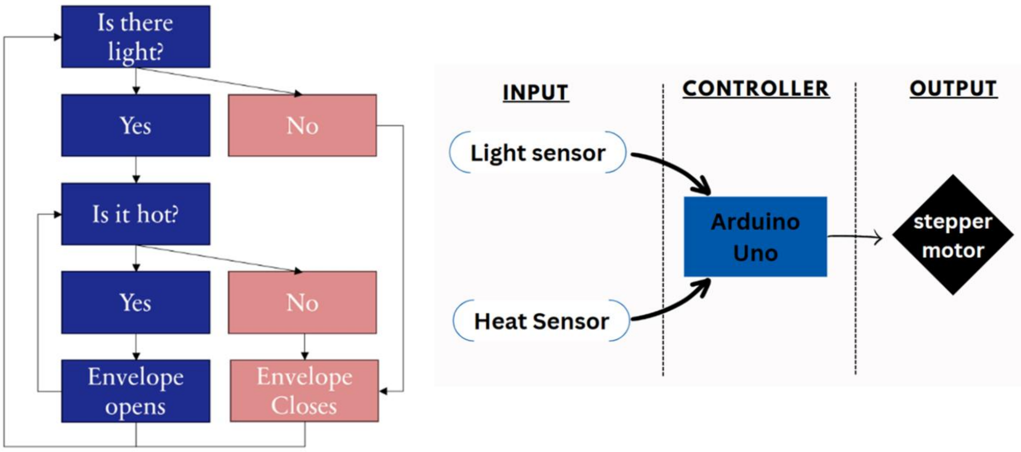


Fig. 7. The circuit logic diagram of how the DFED system operates with the input-to-output sequences and type of sensor used

3.3 User Testing

In this aspect, three individuals with three different backgrounds were acquired to help contribute critical feedback specifically concerning the manufactured prototype. These people were valued to their desired background which was experienced in their respective field of Computer Science, Computing and Product Designing.

3.4 System Evaluation & Testing

Based on user and evaluator feedback, the product has a significant visual appeal, notably the movable canopy feature, which improves customization and repair convenience. However, there are requests for larger sizes to accommodate more people in the shade. In terms of context value, the product is deemed appropriate for hot-weather areas and settings with limited workforce, such as hotels and enterprises. Its capacity to adapt to a variety of environments adds to its appeal and usability.

In terms of innovation, the product's removable canopy component is recognized for its simplicity and customization options, which set it apart from typical umbrellas. Users appreciate the autonomous operation and sensor integration, which contribute to a pleasant user experience. However, feasibility studies reveal hardware limits, particularly in power supply, which pose significant challenges to the project's execution. Despite proficient coding, hardware assembly necessitates specific expertise, and juggling hardware and software duties remains difficult. Overall, while the project concept is deemed sound and practicable, additional work and funding may be required for maximum profitability.

4. Conclusions

In-depth conversations with potential users offered further information about their preferences and concerns regarding shading solutions. Participants were enthusiastic about unique features including replaceable canopies and autonomous functionality.

However, concerns have been expressed about the viability of certain design components, particularly in terms of hardware constraints and code difficulties. These conversations highlighted the need to strike a balance between technological innovation and practical use to achieve customer happiness.

The combination of survey data, interview insights, block model prototyping, and Arduino prototype construction enabled a thorough examination of the suggested shading device. While the study found promising features and functionalities, it also suggested areas for improvement and future development. Moving ahead, tackling technical problems, fine-tuning design components, and emphasizing user feedback will be critical to improving the shading device's overall feasibility and efficacy.

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