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USING DIGITAL SOFTWARE TO DESIGN INTERACTIVE SMART CANOPIES FOR THE OUTDOOR ENVIRONMENT

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Abstract
Introduction: Canopies can serve as valuable elements in the environment when designed to harmonize with their surroundings. Moreover, incorporating recyclable materials in their construction can enhance both their aesthetic appeal and environmental ecological integrity. **This study focuses** on the design and implementation of a responsive canopy that adapts to environmental conditions by employing advanced digital design software. It also aims to promote sustainability through the use of recycled materials, thereby contributing to environmental preservation and reducing negative impacts. **Methods:** The canopy consists of a skin supported by a series of connected forms and features six circular mirrors that rotate about an axis to change their orientation. This innovative approach to intelligent and dynamic skin design is intended to optimize light management and control solar radiation. The portable modules are designed using Grasshopper and Rhinoceros software, in conjunction with Arduino and Firefly, ensuring a seamless integration between physical design and functional operation. These modules are programmed to close during the day and open at night, enabling effective responses to environmental changes. **Results:** The design encourages interactive engagement between the installation and its surroundings by utilizing reflective materials, enhancing both its aesthetic appeal and functional performance. However, it is important to note that the mechanisms controlling the mirror movements present certain functional challenges, requiring ongoing maintenance to ensure optimal performance.

Keywords: smart canopy; Grasshopper and Rhino software; Arduino; Firefly software; digital architecture; environmental response.

Introduction

Architecture merges technical skills with humanistic disciplines such as philosophy and engineering. A professional architect can propose practical solutions that result in attractive and functional designs, though the best option is not always the cheapest or most visually appealing (Mahmoodi, 2001). Debates surrounding appropriate structural forms have emerged in response to significant technological advances over the past two decades. his period, often referred to as the digital revolution, emphasizes the integration of human imagination with digital architectural technologies (Malkin, 2015; Spiridonidis and Voyatzaki, 2009).

The digital era has particularly influenced the contemporary architectural landscape, giving rise to digital architecture. This paradigm shift has introduced innovative concepts in both form and content, driven by advanced technological capabilities. The use of high technology in modern construction has opened new avenues for architectural form-making, structural design, and construction processes. It has also enabled the exploration of novel relationships between architectural form and structure through digital modeling (Petrova, 2017).

Integrating technology into traditional architectural forms is becoming increasingly important in today's rapidly evolving urban context. Smart canopies with interactive digital features represent a fusion of architecture, environmental design, and digital innovation. These structures serve more than just functional purposes; they have the potential to transform outdoor spaces into dynamic environments that respond to user needs and environmental conditions.

The emergence of advanced digital design software has revolutionized the way architects and designers conceptualize and implement smart canopy systems. These tools enable the development of complex models, simulations, and visualizations, allowing for the exploration of interactive features such as lighting, sensors, and responsive materials. By leveraging these technologies, architects can design canopies that not only provide shade and shelter but also engage users through interactive displays, environmental monitoring, and adaptive features.

This approach supports sustainable design strategies, as smart canopies can be programmed to optimize energy consumption, enhance user comfort, and foster social interaction. As urban areas continue to expand and the demand for innovative public spaces increases, the role of digital software in the design of interactive smart canopies will be essential in shaping the future of outdoor environments. Through the integration of technology and creativity, such spaces can enhance quality of

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life, promote community engagement, and adapt to the evolving needs of the environment.

Digital Architecture Importance Review

Globalization and the digital revolution have given rise to concepts referred to as digital forms, which have spread across many disciplines. The idea of contemporary formative theories — which respond to the demands of the modern era by incorporating current theories and trends — includes the philosophy and mindset behind digital forms (Bahlol, 2014).

Digital architecture involves the use of computer processes to design, control, and modify architectural forms. These processes can simulate motion and manipulate forms in a virtual environment that closely mirrors the physical world. This capability allows designers to define, create, and adapt forms in ways that were previously impossible. In digital architecture, a structure is no longer viewed merely as a static frame, as it was in traditional design. Instead, it is conceptualized as a dynamic system, often compared to a living organism imbued with a sense of spirit (Ahmad Fakhrey Farhat, 2021).

Digital architecture also has the potential to bridge Indigenous cultures with advanced technologies used in contemporary architecture and urban planning (Ganji Kheybari et al., 2015; Mahdavinejad, 2020). It is, therefore, regarded as a tool that facilitates and accelerates innovative artistic expression beyond the limitations of traditional methods. From this perspective, computer software can integrate elements and unify structural components, enabling a more fluid interaction between time and space (Ahmad Fakhrey Farhat, 2021; Lienhard and Gengnagel, 2018).

Reducing energy consumption and enhancing human comfort are two fundamental goals of smart building design. A critical topic in this domain is how a building responds to the needs of its users. Such responsiveness may be achieved through mechanical devices or adaptive systems, such as kinetic structural elements that can alter their form and perform intelligent interactions within the built environment — often at minimal cost (Bahlol, 2014). The potential of contemporary digital technologies goes far beyond creating imaginative architectural forms. Their influence extends to building techniques and materials. Digital technology has enabled the development of advanced, innovative materials and has facilitated the integration of traditional materials with microelectronic systems, thereby broadening the scope of architectural possibilities (Digrado et al., 2020).

Intellectual Source of Digital Architecture

Advancements in computer science at the end of the 20th century have significantly affected various aspects of human civilization. In parallel, architectural design has evolved alongside these developments, becoming a crucial medium through which climatic and environmental elements are integrated across multiple disciplines during the digital revolution. This revolution represents the successful convergence of numerous technological innovations (Yang et al., 2023).

The global renewal of digital technologies has given rise to diverse structural systems, each with its own construction methods, materials, forms, functions, and techniques. This evolution reflects the profound impact of the digital revolution. According to recent guidelines for redefining architectural vocabulary (Al-Busaidi and Mohatram, 2020), the building and construction sector has become increasingly interconnected due to ongoing digital advancements. Moreover, digital tools have enabled the creation of geometric forms that cannot be produced using traditional manufacturing techniques (Prado et al., 2019). Digital architecture has transformed the very concept of a building. No longer perceived merely as a static structure, a building is now conceived as a dynamic entity (Şencan, 2023). A key approach within this new paradigm is parametric design technology, which relies on algorithmic thinking to manage and coordinate diverse sets of data. This information is translated into equations or graphs that are applied to the design process, resulting in shapes that are not only efficient and harmonious but also responsive to natural conditions. These forms are developed for specific functions, allowing for the creation of complex, dynamic, and organically structured designs in a systematic manner (Lee et al., 2021). The design process begins with the architect's view of life, which is then materialized using various digital tools and applications such as Autodesk 3ds Max, Grasshopper, and Rhinoceros (Rhino). These programs enable the precise generation of digital designs, including spatially fluid parametric forms whose geometries evolve through a set of mathematical algorithms. These algorithms often involve highly complex equations that cannot be solved through human cognitive capacity alone. Instead, they are executed by computer systems that generate the desired final form through advanced parametric logic (Lagios et al., 2010).

Analysis of Similar Existing Models

Canopies come in various shapes and types. However, it is desirable to be movable to adapt to its optimal functionality. Key factors in canopy design include appropriate size, suitable materials, responsiveness to environmental conditions, aesthetic appeal, lightweight construction, cost-effectiveness, and the ability to create comfortable environmental conditions (Dasari et al., 2023; Nagy and Katona, 2020). It is also essential to consider practical applications and environmental influences. Additionally, addressing psychological comfort is vital for user satisfaction and long-term usability. Therefore, selecting materials that effectively insulate against moisture and heat is crucial.

Elytra Filament Pavilion, Victoria and Albert Museum

The Elytra Filament Pavilion showcases how architectural design can be integrated with civil, environmental, and production engineering to create a unique spatial structure. Rather than presenting a static form, this pavilion exemplifies a dynamic and evolving design. It applies lightweight structural materials inspired by natural forms. The project is the result of four years of research that blends architectural principles with construction techniques and biomimicry. The concept of the canopy draws inspiration from the shape of elytra — the protective front wings of flying beetles. These were recreated using fiber-based structures. The pavilion's composite structure consists of two primary components: the canopy cells and the columns that connect the canopy to the ground, as shown in Fig. 1.

The load-bearing material used in both components is a transparent fiberglass reinforced with black carbon fibers. Each canopy cell is distinguished by the orientation and density of its fiber arrays, which are calculated to meet specific load-bearing requirements. One of the most notable features of these cells is their lightweight composition, which reduces the column weight by approximately 3 kg per square meter. The fiber-based shading not only lightens the structure but also enables measurement of internal forces within the system. The structural system of the canopy responds interactively — it can move, remain stationary, or close as needed Additionally, air humidity and wind fluctuations, which depend on temperature and are determined by thermal imaging parameters, alter the necessary orientation of the canopy to adapt to the environment as needed (Mingallon, 2012; Shareef and Al-Darraji, 2022).

Advantages of this responsive canopy include environmental adaptability, inspiration from natural systems, transparency, flexibility, lightweight design, multifunctionality, and attention to user needs and environmental well-being. Furthermore, the pavilion is scalable and can be expanded to accommodate future design visions (Egi and Eyceyurt, 2022).

Research Project Pavilion, Stuttgart

In the Bioplastic Facade research project, a team of academics and students from the Department of Building and Construction at the Faculty of Architecture, University of Stuttgart, developed a prototype for fully recyclable window coverings made of bioplastic material composed of more than 90% recyclable content (Fig. 2) (Shu et al., 2020).

The project aimed to fully leverage digital technologies to rethink conventional design and construction methods. This goal was achieved through the integration of advanced architectural design and computer engineering techniques, automated construction processes, and innovative human-machine collaboration. The project featured a bio-inspired polymer facade system, forming a thin, 145-square-meter shell shaped like a twisted horseshoe and held together with metal screws. Triangular bioplastic units were designed, precisely positioned, and assembled on a metal mesh frame to form the overall structure. Pyramidal openings and geometric patterns were fabricated using a CNC machine, as shown in Fig. 2. The resulting structure is a weather-resistant and self-supporting building envelope (Chairiyah et al., 2022; Köhler-Hammer and Knippers, 2014).

Canopy Concept: ICD/ITKE Research Pavilion

The University of Stuttgart's ICD (Institute for Computational Design and Construction) and ITKE (Institute of Building Structures and Structural Design) introduced an innovative research pavilion to demonstrate automated textile-based production techniques for constructing customized wooden shells. This project marked the first architectural application of industrial sewing techniques for wooden components, representing one of several successful research initiatives exploring computational design, modeling, and fabrication in architecture. The pavilion was a collaborative effort involving students and researchers from various fields, including architecture,

Fig. 1. Method of making the Elytra canopy (Prado et al., 2019)

Fig. 2. Interface model for durable and recyclable bioplastics, Stuttgart, 2013

engineering, biology, and paleontology (Sonntag et al., 2017). Industrial sewing was employed not only to minimize warping but also to connect multiple double-curved panels into a cohesive structural unit, as illustrated in Fig. 3. An industrial robot was used to assist in the assembly of the panels, bending each one to the required curvature and fixing it in place using sewing machines. This method enabled the industrial application of curved wooden components. However, one issue encountered during implementation was ensuring the long-term stability of the project against wind and thermal change (Schwinn et al., 2016). The use of volumetric, curved sheet units enabled the construction of a larger architectural form using standardized sheet materials (Lienhard and Gengnagel, 2018).

Pavilion Canopy in Melbourne, Australia

This canopy is notable for its dynamic response to weather conditions and its attempt to replicate the audio-visual experience of an urban rainforest.

Fig. 3. New research pavilion with wooden shell structure (Schwinn et al., 2016)

Designed by Amanda Levete, a London-based architect, the pavilion features a stunning outdoor forest canopy designed for Melbourne. The architectural concept drew inspiration from modern marine technology. The canopy incorporates carbon fiber slats and is inspired by rose petals, designed to sway gently in the breeze. It supports a transparent roof, as illustrated in Fig. 4. Despite their delicate appearance, the “petals” were fabricated from composite materials with physical properties similar to those used in sailboats. Each petal is less than half an inch thick and measures between 10 and 16 feet in width. At the same time, the petals acted as speakers, allowing the canopy to pick up and process everyday noise. Carbon fiber speakers were integrated into the canopy structure, enabling it to respond to environmental stimuli. Rather than remaining static, the canopy moves with the wind. In motion, it resembles a semi-circular floral wall, rising with radial, petal-like shields. LED lights have been added to the speakers to enhance the visual experience. Together, the sound and light features created a vibrant viewing area, offering views of the Melbourne skyline to the north (Petrova, 2017).

Materials and Methods

Software Applied for Analysis and Design of the Experimental Canopy

Rhino 3D and Grasshopper

Rhino 3D has emerged as a preferred tool for addressing complex formal design challenges. Grasshopper, an open-source visual programming language and environment, operates within the Rhinoceros 3D application. It complements Rhino by simplifying the design process and enhancing connectivity between design components.

Grasshopper and Rhino are among the most widely used software programs in biomimetics and architecture in the globalization era (Mingallon, 2012). Grasshopper offers the unique advantage of efficiently generating a wide variety of forms and materials through mathematical and parametric calculations. It is particularly effective for translating natural inspiration into human-made technology, as it can accurately render the complexity of natural patterns in tangible forms (Dananjaya et al., 2024). The Grasshopper plugin helps develop algorithms, whereas Rhino can be used to construct models of more intuitive methods. As a result, Grasshopper and Rhino used a graphical engineering approach that can facilitate the production of models by architects without requiring them to study texts (Castro Pena et al., 2021). Grasshopper facilitates parametric and algorithmic modeling, offering countless design variations and creative possibilities. As a plugin for Rhino, it enhances Rhino’s already fast and user-friendly capabilities, making it a popular choice in many creative sectors. Together, these tools allow designers to quickly generate parametric shapes (Castro Pena et al., 2021; Shareef and Al-Darraji, 2022).

Arduino Software

Arduino is an open-source platform used to develop electronic projects. It consists of a physical programmable circuit board (microcontroller) and an Integrated Development Environment (IDE) that runs on a computer. The IDE is used to write and upload code to the Arduino board. Arduino is used extensively in interactive and robotic projects. It connects with various sensors to interact with the physical world and then processes sensor data through pre-coded logic. Based on this analysis, the Arduino board can control outputs like motors, lights, or sound devices (Manual, 2024).

Firefly Software

Firefly is a downloadable plugin for Grasshopper that bridges the digital and physical realms. It allows

Fig. 4. Pavilion in Melbourne, Australia (Petrova, 2017)

data to flow between the digital and physical worlds in real-time to enable the creation of virtual and physical prototypes with unprecedented smoothness (Mingallon, 2012). Fig. 5 shows the software components applied in this study to design the smart canopy.

Methodology for Building a Basic Prototype

Basic Steps to Create a Physical Model Simulating Engine Movement

This section outlines the tools, materials, and procedures used to build the physical models and apply electronic techniques. The process of creating the proposed model can be divided into five main stages, as described below:

Stage 1: The basic design of the dynamic units was created using the Grasshopper plugin. In this stage, the proposed movement pattern of the units was developed, with vertical motion selected as the primary movement. The rotation occurred around the vertical axis, and the proportion of opening and closing was also determined. Fig. 6 illustrates the process of designing the dynamic units, and Fig. 7 depicts the opening and closing stages.

Stage 2: This stage involved designing the sections of the physical model. Rhino software was used to create the 3D model, which helped visualize how the dynamic units would move and how various parts would interact. Additionally, the model components were prepared for laser cutting by drawing them in 2D. The unit components and the external support structure were drawn using Rhino, as shown in Fig. 8.

Stage 3: The physical model was assembled. A 3 mm thick high-density fiberboard (HDF) was used to construct the main structure, assembled to simulate the model movement realistically. A plastic mirror — chosen for its lightweight, weather-resistant, and eco-friendly properties — was used for the dynamic elements. The parts were cut with a laser, as shown in Fig. 9. The outer plastic frame of the circular shapes served as the support structure for the moving units. Strong wire was used as the vertical axis to control the movement of the circular components. The plastic circular frame was mounted on the HDF structure for added strength and durability. The moving units were fixed in place using strong Maftol resin adhesive, and the frames were securely bonded together, as illustrated in Fig. 9.

Sensors were installed to capture light intensity readings relative to engine movement angles. The sensor unit records maximum values — typically around 1,000 — under soft daylight conditions, and

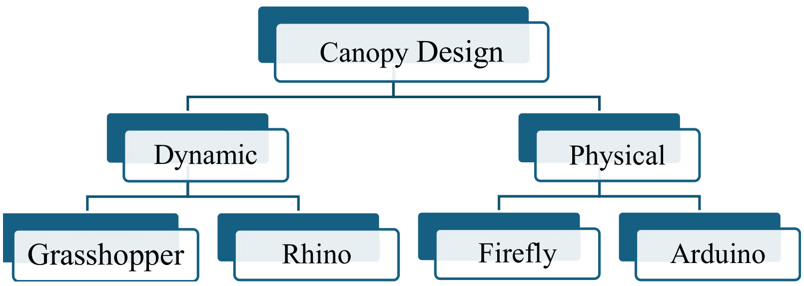


Fig. 5. Software components applied to design the canopy

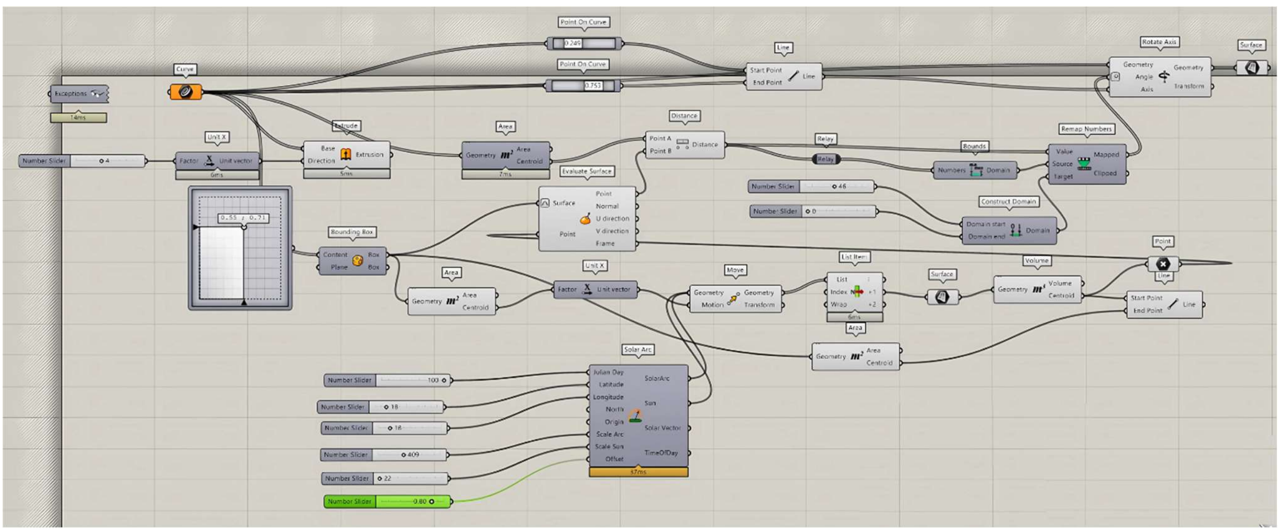
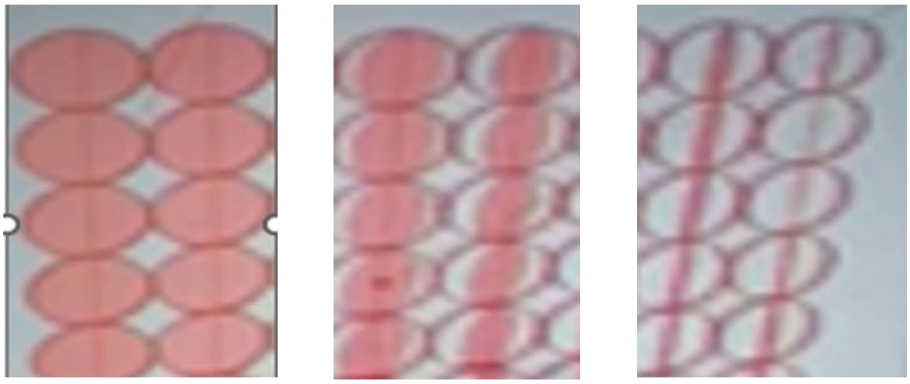


Fig. 6. Process of designing dynamic units



Fully closed 75% open Fully open

Fig. 7. Unit movement stages

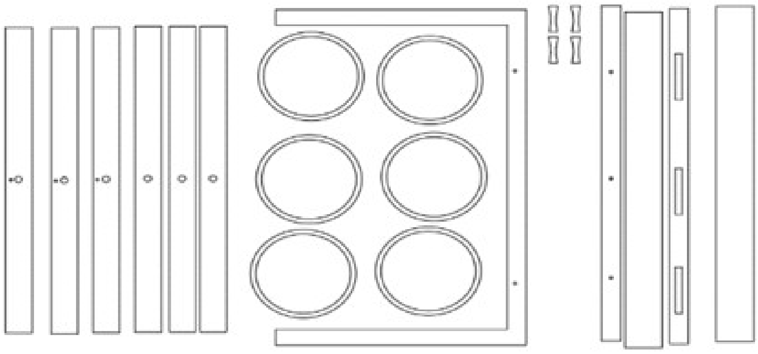


Fig. 8. Design of dynamic unit sections for laser cutting

Fig. 9. Components of the physical model and dynamic units

minimum values during sunset, nighttime, or when sunlight reaches the sensor at oblique or indirect angles. An engine movement value of zero indicates that the unit is in a closed state during clear weather, while a maximum value of around 90 indicates a fully open dynamic unit during periods of darkness. These sensor units were positioned perpendicular to the external support structures.

The canopy was designed to dynamically and intelligently respond to light, adjusting its opening and closing behavior accordingly. In this study, an Arduino unit board was used to connect sensors to rotate the moving parts of the modules when the sensor senses sunlight and the major part of the physical part that simulates the motor's movement, as illustrated in Figs. 10 and 11.

Fig. 12 shows the inputs and outputs of the Arduino board, which was connected to Grasshopper via the Firefly plugin. They were connected to the real world via this extension of the virtual world. The Arduino board continuously read sensor data and movement parameters, which were crucial for enabling dynamic responses of the engineered units to external environmental conditions. To construct the physical model, three motors were used. Each motor was connected to a vertical axis, with one side linked to the motor and the other to the Arduino board (Fig. 13). Using Firefly, the physical

Fig. 10. Steps in the physical model building process

Fig. 11. Configuration of moving units

model was linked to numerical readings, and motor movement was programmed to operate between 0 and 90 degrees. Based on the sensor readings, the motors adjusted the position of the units accordingly. To move three motors and provide power, an input voltage of 12 Volt was used for the motors because the output voltage of the Arduino board was 3.3 V and 5 V, whereas the motors with low power and voltage did not respond to the structure movement.

The dynamic units rotate along a vertical axis, starting from a 0-degree angle — which represents the fully closed position during daytime — up to a 90-degree angle, indicating the fully open position at night or under cloudy weather conditions. Fig. 14 illustrates the final form of the model.

Stage 4: Identifying the electronic components required to connect and operate the physical model. Various physical innovation tools were used to simulate the motor-driven movement of the proposed dynamic interface, as illustrated in Fig.15.

Stage 5: A method was developed to adapt the canopy system to variable weather conditions by using an Arduino control board. This enabled real-time interaction between environmental conditions and simulation software, allowing the geometric form of the canopy to adjust based on the sun's orientation. An LDR (Light Dependent Resistor) sensor was incorporated to monitor light intensity,

Fig. 12. Inputs and outputs of the Arduino control board connected to Grasshopper

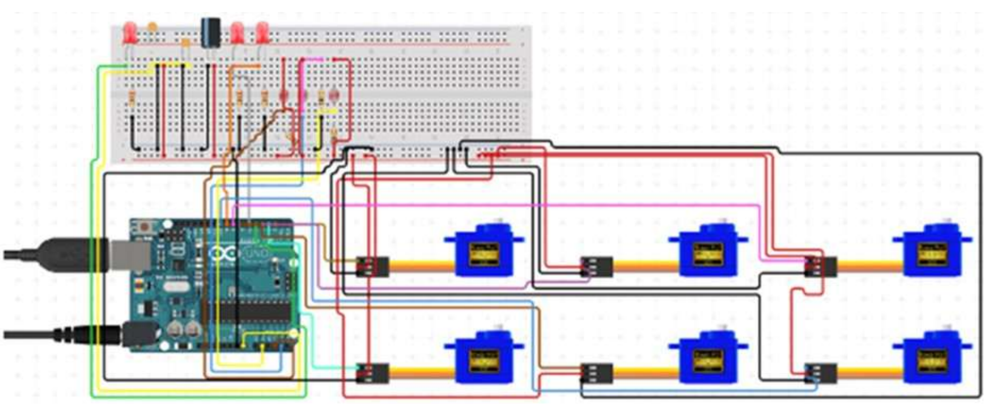


Fig. 13. Electrical circuit simulation of the physical model, showing motor and sensor connections to the Arduino board

Fig. 14. Final form of the composite material configuration

with its data linked to the motor’s movement angle. This process utilized a Remap function to filter the maximum and minimum light readings from the sensors. The corresponding minimum and maximum angles of servo motor movement were then entered into the target section. Fig. 16 illustrates the reset parameters used for reading light intensity.

The highest sensor reading from the simulation under clear and sunny conditions is 850, while lower values corresponds to readings under cloudy skies or at night. For the servo motor, the lowest movement value indicates that the modules are closed — typically when sunlight is directly vertical on the dynamic units during clear weather. A value

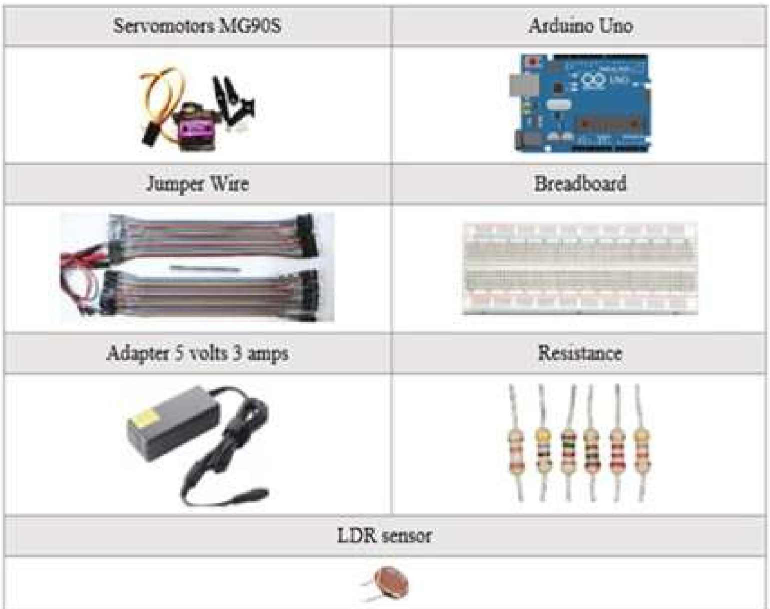


Fig. 15. Physical tools used to build the physical model

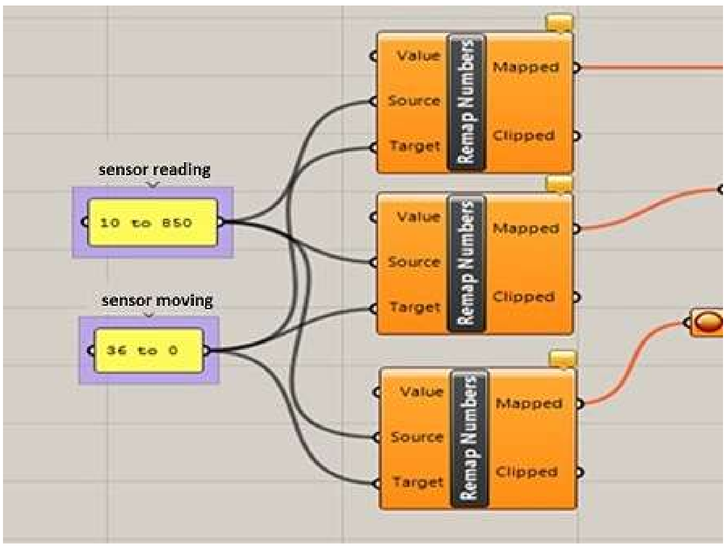


Fig. 16. Reset parameters for reading the light and motion sensor values

of 36 represents the maximum angle of servo motor movement. The study of the motor's motion and the behavior of the dynamic units in the physical model demonstrated that at an angle of 36 degrees, the units are fully open and oriented perpendicular to the supporting structure. When the modules are closed, the interior lighting decreases. To address this, the designer implemented a mechanism where reduced interior lighting causes the LED to glow more brightly. Conversely, when interior lighting is sufficient, the LED brightness decreases — eventually reaching zero — based on the external light readings. Fig. 17 illustrates the minimum and maximum LED reading values.

The controller board is connected to Grasshopper via the Firefly plugin. Fig. 18 depicts the inputs and outputs of the Arduino board: the sensor module readings act as primary inputs of the light intensity and the motor movement values are the main outputs as a response to the sensor's action. Each motor operates independently, and the same process is applied to control the corresponding LED.

Grasshopper was used to design the final virtual 3D canopy form. The Lumion program was then utilized to render the final visual representation of the design (Fig. 19). Fig. 20 shows a 3D conceptual visualization of the canopy.

Results and Discussion

Rhino 3D and Grasshopper Plugin

When using Rhino 3D for designing smart canopies, its most significant feature is arguably its parametric modeling capabilities, especially when integrated with the Grasshopper plugin. Grasshopper enables architects to create algorithms that define relationships between various design components — an essential function for smart canopies, which must often adapt to environmental factors such as daylight, wind, and load conditions. Grasshopper's parametric tools provide real-time visual feedback, allowing designers to quickly and efficiently explore multiple design iterations. This capability is particularly valuable for optimizing the form and functionality of canopies based on specific performance criteria.

Additionally, Grasshopper can be linked to external data sources, allowing designers to incorporate real-time environmental data into their models. This feature is crucial for developing

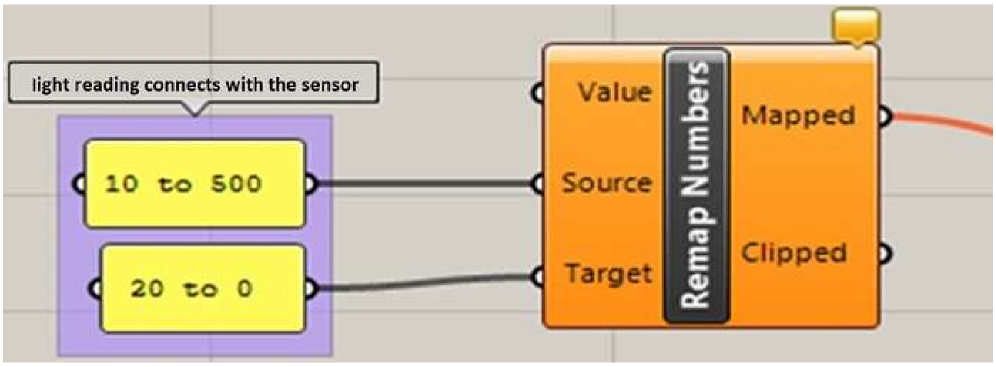


Fig. 17. Minimum and maximum LED reading values

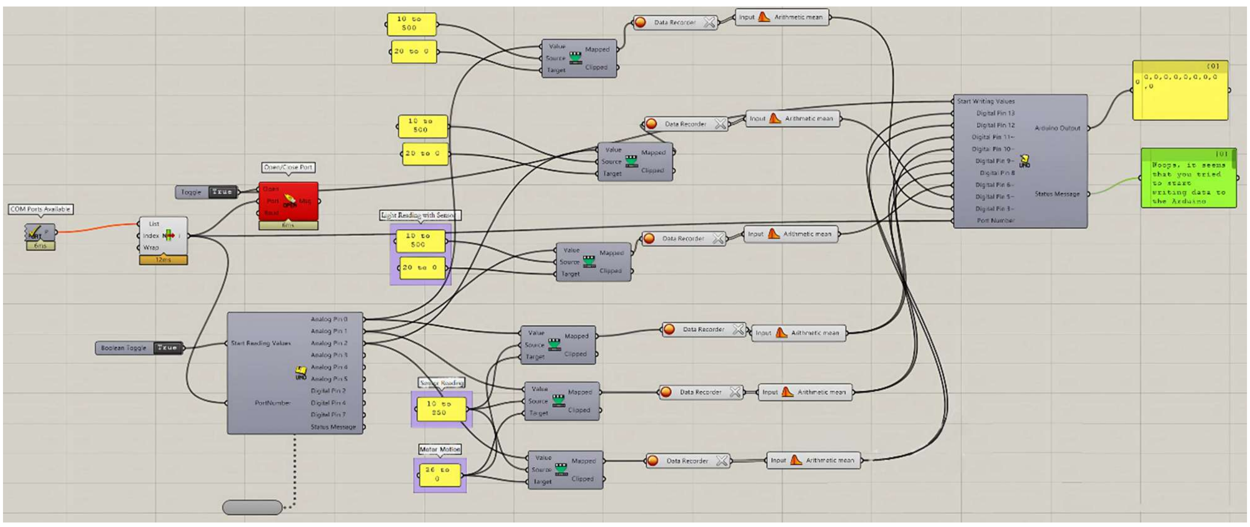


Fig. 18. Arduino board definition strategy in Grasshopper

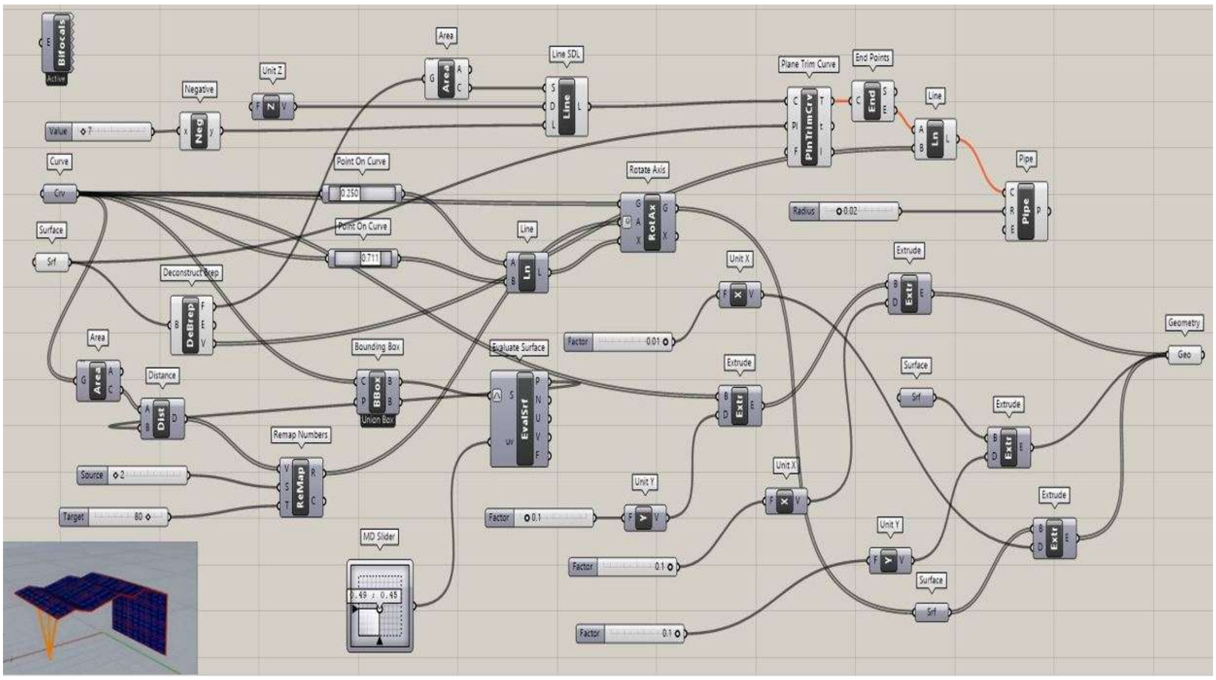


Fig. 19. Final design of the canopy using the Grasshopper plugin

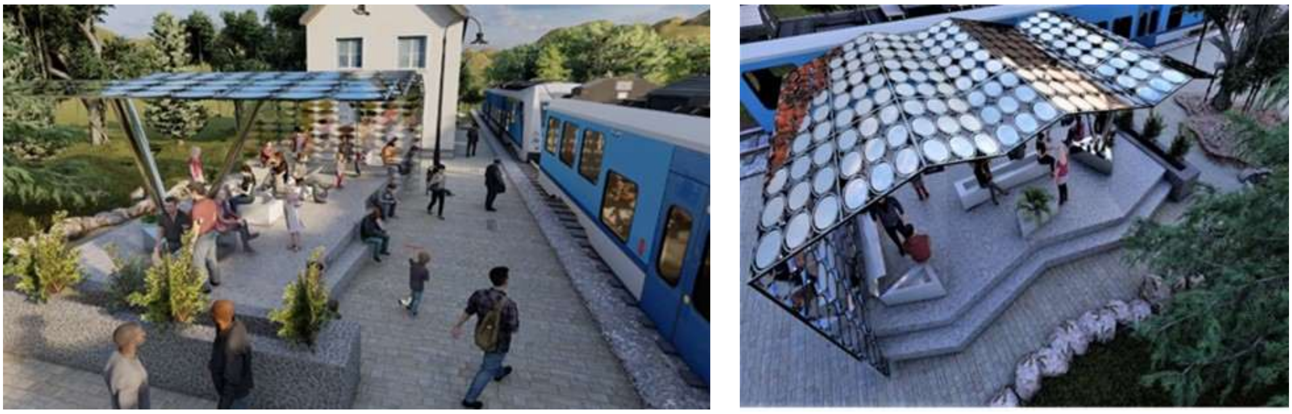


Fig. 20. 3D conceptual visualization of the canopy

canopies that dynamically respond to changing weather conditions and user requirements. Its powerful handling of curves and surfaces also supports the design of complex, organic forms that are often desired in contemporary architecture.

Moreover, Grasshopper automates repetitive modeling tasks, allowing architects to focus more on creative aspects of design rather than manual adjustments.

Overall, Rhino's compatibility with a wide range of tools and plugins enhances its versatility, enabling seamless integration with structural analysis software and rendering tools that are essential for improving the performance of smart canopies.

Arduino Software

When using Arduino to manage a canopy system, the connection of sensors and motors can significantly affect the system's efficiency, responsiveness, and reliability. Several key factors influence these performance aspects:

1. *Connection Methods and Wiring Configuration:* Sensors and motors can be connected using either digital or analog signals. Digital signals offer clear open/close states, making them easier to implement, while analog connections provide more detailed data — such as the precise canopy angle — but require more complex processing.

There are two primary wiring configurations: star and daisy chain. In a star connection, each sensor and motor links directly to the Arduino, whereas, in a daisy chain configuration, the tools are connected in series which can impact response time and troubleshooting.

2. *Sensor Integration:* The effectiveness of sensor integration depends on the sensor type and debouncing technique. Limit switches, used to detect fully open or closed positions, can provide

reliable feedback. Proximity sensors help detect obstructions and enhance safety. Debouncing — implemented in software — is essential to avoid false signals caused by mechanical switch noise during transitions.

3. *Motor Control:* This depends on the type of motor and its associated driver circuit. Common motor types used with Arduino include DC motors, stepper motors, and servo motors. The selection affects precision and power consumption. Servo motors provide accurate positioning, while DC motors require additional feedback mechanisms. Using appropriate motor driver circuits allows precise control over motor direction and speed, which directly affects the opening and closing speed of the canopy.

Proposed Site for the Canopy

The proposed location for this project is a temperate climate with an aesthetically pleasing environment, where the canopy's mirrored surfaces can reflect the surrounding beauty. The smart canopy is designed to enhance user experience by dynamically responding to lighting conditions, enabling effective control of sun exposure and shade. This design aims to improve environmental comfort while aligning with community expectations. Inspired by natural interaction systems, the canopy continuously adapts to changing conditions and the needs of outdoor users. Its functionality allows for shape modification through flexible materials, ensuring structural integrity throughout its operational life.

Conclusions

This study discussed the design and implementation of smart canopies using the computer programs Grasshopper, Arduino, and Lumion to blend aesthetic qualities with advanced technology, resulting in a practical design that is visually striking and in harmony with the surrounding environment. The following conclusions can be drawn:

1. Using lightweight natural materials such as carbon, cellulose, and glass fibers is an effective approach for producing smart canopies that respond to environmental factors like light, wind, and humidity through sensors controlling canopy movement. Advantages of this responsive canopy include environmental adaptability, inspiration from natural systems, transparency, flexibility, lightweight design, multifunctionality, and attention to user needs and environmental well-being.
2. Recycled materials can be used to manufacture smart canopy membranes, providing environmentally friendly and lightweight solutions.
3. Employing digital software such as Grasshopper and Rhino for intelligent canopy design offers significant benefits. These tools enable complex parametric modeling, allowing architects to explore creative shapes and configurations that respond dynamically to environmental conditions. The integration of real-time data supports adaptive configurations, enhancing both functionality and sustainability.
4. The combined capabilities of these software programs streamline the design process and facilitate more effective interaction among users. Using Grasshopper and Rhino improves both the aesthetic and functional aspects of smart canopies, contributing to more sustainable and responsive architectural solutions.
5. Smart canopies can be designed to mimic the interactive behaviors observed in living organisms, enabling them to continuously adjust to changing environmental conditions and the needs of outdoor users.
6. The design concept can originate from the site itself, reflecting the exterior environment of the implemented design and emphasizing the connection between human heritage and nature.

Data Availability Statement

The data supporting the findings of this study are available from Ayam Sh. Altameemi upon reasonable request.

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ИСПОЛЬЗОВАНИЕ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ ДЛЯ ПРОЕКТИРОВАНИЯ НАРУЖНЫХ ИНТЕРАКТИВНЫХ УМНЫХ НАВЕСОВ

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Аннотация

Введение. Навес может служить важным элементом окружающей среды, если он спроектирован в гармонии со своим окружением. Кроме того, использование перерабатываемых материалов в конструкции навеса может повысить как его эстетическую привлекательность, так и экологическую целостность среды. **В данном исследовании основное внимание уделяется** проектированию и реализации адаптивного навеса, который подстраивается под условия окружающей среды с помощью современного программного обеспечения. Кроме того, его цель заключается в содействии устойчивому развитию посредством использования переработанных материалов, что способствует сохранению окружающей среды и снижению негативного воздействия на нее. **Методы.** Навес состоит из оболочки, поддерживаемой рядом взаимосвязанных форм, и включает шесть круглых зеркал, которые вращаются вокруг своей оси, меняя свое положение. Данный инновационный подход к проектированию умной динамической оболочки направлен на оптимизацию регулирования освещения и инсоляции. Мобильные модули были спроектированы с использованием программ Grasshopper и Rhinoceros в сочетании с Arduino и Firefly, с обеспечением бесшовной интеграции между системой и ее функциональной работоспособностью. Модули запрограммированы так, чтобы закрываться днем и открываться ночью, что позволяет эффективно реагировать на изменения окружающей среды. **Результаты.** Дизайн обеспечивает интерактивное взаимодействие между установкой и ее окружением за счет использования отражающих материалов, улучшая как эстетическую привлекательность, так и функциональные характеристики конструкции. Однако стоит отметить, что механизмы, управляющие движением зеркал, имеют определенные сложности и требуют регулярного технического обслуживания для обеспечения оптимальной работы.

Ключевые слова: умный навес; программное обеспечение Grasshopper и Rhino; Arduino; программное обеспечение Firefly; цифровая архитектура; реакция на окружающие условия.