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Research on Green Modular Disaster Prevention Product Design and Spatial Configuration Strategy Based on AHP-GIS

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Abstract: Facing persistent natural catastrophes, the necessity for disaster prevention products in afflicted cities becomes paramount. Modular design has proven to be a viable method for streamlining transportation and manufacturing processes for disaster prevention products. However, existing post-disaster prevention products often fail to incorporate the green modular concept, with limited research on spatial allocation strategies. In response to the current challenges, a new breed of green post-disaster prevention products is urgently warranted to mitigate the impact of major natural disasters and safeguard lives and property. To achieve the goal, this study employs a combined analytic hierarchy process (AHP) and geographic information systems (GIS) analysis to propose an inflatable cabin for emergency disaster prevention, specifically designed for flood scenarios. Using the inflatable cabin as an empirical case, this study introduces a layered design approach progressing from macro to meso and then to micro levels to construct an objective decision-making model to prioritize key design elements, develop spatial post-disaster prevention strategies, and analyze the mechanical performance. Results indicate that at a distance of 30 m from the base of the slope (SPIC), the impact force is most significant, reaching up to 1.8×10^7 kN. As the distance increases from 30 m to 150 m, the maximum impact force decreases by an order of magnitude, and the average impact force decreases by approximately two orders of magnitude. Furthermore, this comprehensive approach, which starts from a holistic design perspective and culminates in optimizing individual disaster structures, offers practical significance for engineering design research.

Keywords: modular design; disaster prevention; product design; AHP-GIS analysis method; flood refugees; numerical simulation; sustainability

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1. Introduction

The combination of excessive urbanization and global climate change has exacerbated the escalation of natural disasters in magnitude, frequency, and severity in afflicted cities. The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) is one of China's most open and economically dynamic regions, characterized by rapid urbanization and a sharp growth in population within China's coastal regions. The frequent human activities have jeopardized the region landform and accordingly relocated the population [1]. Such combination has amplified the vulnerability of weaker communities to disasters, therefore leading to a significant portion of residents being exposed to disasters in the GBA. Additionally, due to global climate change, excessive rainfall and flooding pose year-round challenges to the region's inhabitants [2]. Natural catastrophes underscore the unpredictable nature of disasters, the scarcity of resources in affected areas, and the swift environmental transformations that exacerbate vulnerabilities [3]. These calamities engender a rise in "environmental refugees", individuals compelled to seek new habitats due to environmental degradation.

Considering these challenges, the necessity for disaster prevention products in afflicted cities becomes paramount. Such products provide safety, protection, emergency response, rescue, and recovery functions before, during, and after a disaster [4]. The adoption of modular design in disaster prevention products has led to benefits such as reduced manufacturing costs, increased productivity, and lower energy consumption [5], therefore enhancing the adaptability and promptness of these solutions. Modular design has therefore been widespread applied in various disaster prevention products, including earthquake emergency housing, flood protection walls, air purification, and domestic waste treatment.

However, limited research has concentrated on post-disaster prevention products [6]. The current research emphasizes pre-disaster and disaster prevention products, neglecting the significance of post-disaster prevention products [7]. Despite this, the existing research may also guide critical pathways for the optimization of post-disaster product designs in terms of environmental sustainability awareness [8,9], humanization and personalization [10], ease of operation and maintenance difficulty [11], traditional form and functionality [12], and comfort and ergonomics [13]. A new breed of post-disaster prevention products is urgently warranted to mitigate the impact of major natural disasters and safeguard lives and property.

Another gap is the absence of post-disaster prevention products incorporating the concept of modular design at multiple scales. While modular design can streamline transportation and manufacturing processes for disaster prevention products [5], its integration into post-disaster solutions remains limited, lacking a holistic approach and struggling to balance individual design aspects with spatial allocation strategies at different scales [14,15]. The concept of module design can make the post-disaster products more extensively applicable and comprehensive at multiple scale.

Therefore, utilizing the design of the emergency disaster prevention inflatable cabin (EDPIC) in Zhuhai City as an empirical case, this study aims to: (i) formulate spatial strategies of post-disaster prevention products based on population density and disaster-affected areas; (ii) construct an objective decision-making model to prioritize key design elements and develop a disaster prevention product strategy using the concept of modular design; and (iii) discuss the mechanical performance of the EDPIC in earthquake-prone regions through numerical simulations across various scales.

2. Literature Review

2.1. Hazards of Natural Disasters

The combination of natural hazards and vulnerabilities that jeopardize weaker communities that cannot overcome the resulting adversities is known as a natural disaster [16]. Humans are constantly in danger from both natural and man-made disasters, which frequently cause enormous harm, human misery, and detrimental effects on the economy. Figure 1a shows that flood disasters manifest in two primary forms: ordinary flooding and debris flow disasters. It is essential to distinguish between these two forms, understand their unique characteristics, and comprehend their interrelation. Ordinary flooding occurs when a water body, such as a river or a lake, overflows its banks due to heavy rainfall, snowmelt, or dam failure. Frequent human activities can lead to ordinary floods, causing damage to infrastructure, property, and agriculture. They can also lead to community displacement and threaten human life [17]. Debris flow, often called mudflow, is a rapid mass movement of water, sediment, and debris down a slope. It is usually triggered by intense rainfall or rapid snowmelt. Debris flows contain a significant proportion of sediment, including rocks, boulders, and mud. The mixture rushes and can have devastating consequences. These severe consequences can include the loss of human life; the destruction of houses and facilities; damage to roads, rail lines, and pipelines; vehicle accidents and train derailments; environmental damage from product spills; damage to agricultural land, livestock, and forest lands; the disruption of water supply system; the devaluation of fisheries; and many other losses that are difficult to quantify [18].

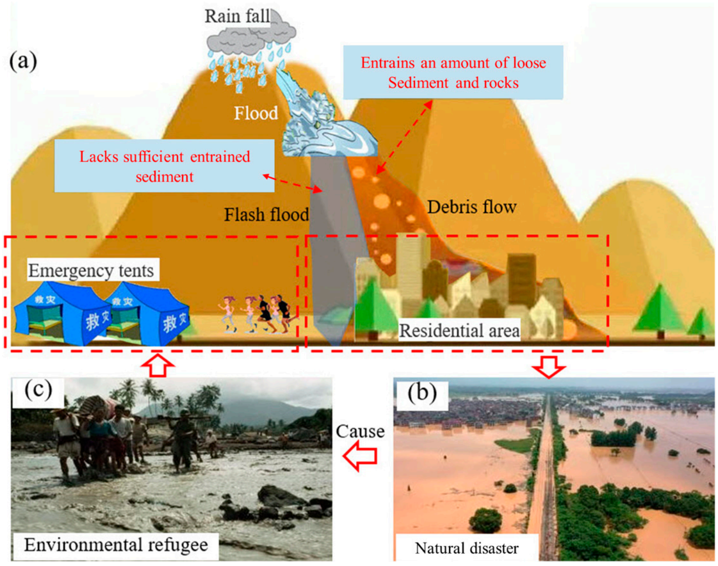

Figure 1. Current situation of a natural disaster. (**a**) The forms and consequences of flood disasters. (**b**) Natural disaster (https://cn.nytimes.com/china/20220624/china-floods-heatwaves/ (accessed on 24 June 2022)). (**c**) Environmental refugees.

Figure 1b presents natural catastrophes characterized by their unpredictable nature, the availability of few resources in the affected areas, and rapid environmental changes [2]. Due to different natural disasters, there are “environmental refugees”. They are individuals who, due to drought, soil erosion, desertification, and other environmental issues, can no longer make a stable living in their former homelands. Figure 1c shows that they feel they have no choice but to look for safety elsewhere out of desperation, no matter how risky the endeavor [19]. Thus, disaster prevention products in disaster-stricken cities are essential, and according to the number of individuals affected by disasters over the years, the demand level for disaster prevention products is also worth considering. Taking emergency tents as an example, the existing ones have the following disadvantages: (1) the internal comfort is poor, and the thermal insulation ability is not good; (2) they require a workforce to build, and the scrapped tents are not correctly disposed of, which will quickly cause environmental pollution; (3) storage issues need to be considered for emergency tents to be used, which require ample storage space and are inconvenient to transport; (4) their impact resistance is poor, and their ability to protect against debris flow disasters caused by floods is weak. Therefore, there is an urgent need to develop a new type of green disaster prevention product to deal with major natural disasters and ensure the safety of people’s lives and property.

Additionally, due to global climate change, extreme precipitation has increased in the GBA in magnitude, frequency, and severity. Climate change and urbanization have contributed to increased extreme precipitation occurrences and severe urban inundations in the GBA [17]. Thus, taking the GBA as an example, flood disasters have had a specific impact on the mega-urban agglomeration. For instance, the super typhoon “Mangkhut” from 2018 made landfall in Guangdong with maximum winds of 45 m/s in the center at touchdown, resulting in direct economic losses of 5.2 billion yuan, affecting roughly 3 million people, and evacuating and relocating 1,161,000 people. In Guangzhou in 2020, the “5-22” downpour caused the amassing of water in 443 locations throughout the city, flooding in numerous areas, and the suspension of Metro Line 13 [18]. For Guangzhou, the active application of disaster prevention products is imperative.

2.2. Current Status of Disaster Prevention Product Development

Disaster prevention products are products designed to provide safety, protection, emergency response, rescue, and recovery functions before, during, and after a disaster;

they should have the characteristics and needs of protection, reliability, adaptability, environmental friendliness, maintainability, intelligence, and economy [4]. The US Federal Emergency Management Agency (FEMA) emphasized the protective, emergency, and sustainable nature of disaster prevention products [20].

However, most of the disaster prevention design products focus on the pre-disaster and disaster period while neglecting the post-disaster period [6]. In the face of diverse and complex natural disasters, existing disaster prevention products have certain advantages and characteristics regarding safety, reliability, functionality, and inclusiveness, but they still need to be improved. In this regard, the following points are summarized as critical directions for the optimization of post-disaster product design:

(1) Environmental sustainability awareness: Priority should be given to the use of environmentally friendly materials to improve the sustainability and quality of disaster prevention products [8], while sustainability is essential in post-disaster recovery and reconstruction [9].
(2) Humanization and personalization: Based on the user's physical and mental experience, post-disaster product design should meet specific environmental integration and visual aesthetic needs [10] and be dedicated to providing a "human-centered" humane recreation experience.
(3) Ease of operation and maintenance difficulty: Most disaster prevention products have a complex operation process and must be more convenient. Maintaining and cleaning the products is also problematic, requiring professional staff to handle and replace them [11].
(4) Traditional form and single function: Many existing disaster prevention products are only for a particular natural disaster or an emergency scenario, cannot meet comprehensive disaster prevention needs, and require more innovation [12].
(5) Comfort and ergonomics: When responding to natural disasters, the comfort and ergonomics of equipment are crucial [13].

Finally, existing research on post-disaster prevention product design needs to do more to explore the relationships among the distribution strategies of disaster prevention products within the affected area to form a complete design strategy. Mainly based on supply and demand matching, this can better meet the refuge requirements of demand points and improve the rationality of the spatial layout of disaster prevention products [21].

2.3. Current Status of Green Modular Product Design Research

In modular design, complex products are decomposed into standardized modules in the design and manufacturing process through system integration principles to achieve efficiency and excellence in product design, resulting in lower manufacturing costs, higher productivity, lower energy consumption, and lower waste generation. Masato explored the application of modularity in product design [22].

Conducting a product life cycle assessment allows for a comprehensive measurement of the environmental impact of a product, which identifies the best strategies for using, maintaining, and disposing of the product to reduce environmental hazards. The life cycle model [23], developed by Japanese electronics manufacturer Panasonic, enables developers to assess, plan, and implement the environmental impact of product manufacture, use, and recycling from the design stage onwards.

The application of modular design in the field of disaster prevention is mainly for the development and manufacture of disaster prevention products, which are currently applied in four areas: modular design of earthquake emergency housing, modular design of flood protection walls, modular design of air purification, and modular design of domestic waste treatment.

Modular designs are widely employed for earthquake-resistant emergency housing. Amatrice Town utilized lightweight, eco-friendly materials and modular manufacturing to greatly reduce cost and time in producing post-earthquake emergency housing [24], which is shown in Figure 2a. To prevent flood damage to buildings and crops, flood protection walls commonly adopt modular designs with better waterproof performance and adaptability. Chen Su proposed the extensible mobile flood control wall in underground using a modular design approach, which, depending on the environment and needs, is shown in Figure 2b. The extensible mobile flood control wall in underground can be flexibly assembled and disassembled according to different settings and needs [25]. To cope with the impact of natural disasters and environmental pollution on indoor air quality, the air purification modular design offers different functions and filtration effects on various pollution sources [26]. For waste and domestic waste caused by large natural disasters, the modular design for domestic waste treatment uses renewable energy and environmentally friendly materials with flexible and efficient treatment capacity and low energy consumption characteristics [27].

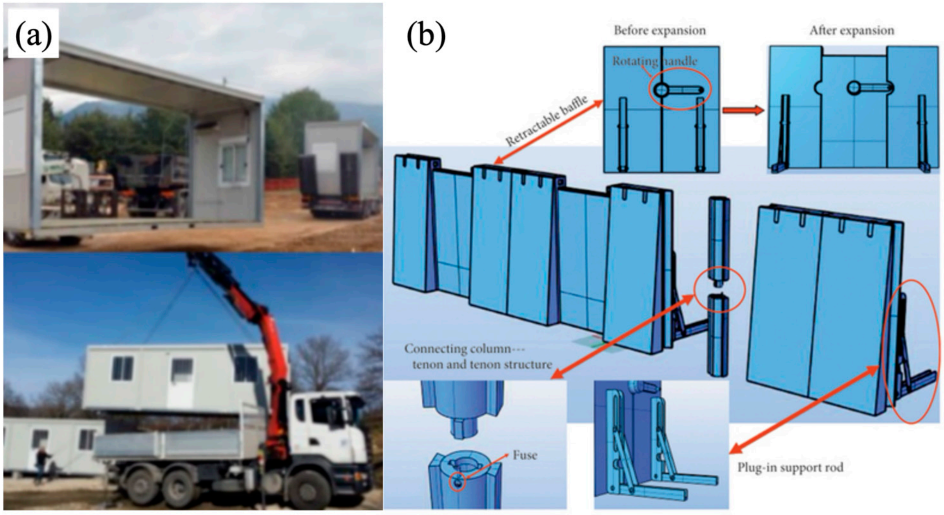

Figure 2. Application of the green modular concept in the field of disaster prevention product design. (**a**) Temporary housing in Amatrice Town after earthquake. (**b**) Extensible mobile flood control wall in underground.

Modular design should continue to be vigorously developed in the future design process of disaster prevention product development [28]. Based on the inevitable trend of sustainable development, the promotion and application of green modularity in the field of disaster prevention product design is expected to improve the adaptability, sustainability, and intelligence of products; reduce manufacturing costs and time; and lay a good foundation for enhancing the physical and mental experience of users after disasters [2].

3. Research Methodology

The whole methodology was divided into four steps, namely literature analysis, user need assessment, and mechanical performance simulation (Figure 3). The details of the research methodology are as follows: (1) Literature analysis: A thorough review of existing literature helps to highlight the gaps and areas for improvement in disaster prevention strategies and identifying the shortcomings of current disaster prevention products, with a particular focus on post-disaster scenarios. This foundational research provides the context and rationale for developing more effective solutions tailored to the needs of flood refugees in the GBA. (2) GIS method: Utilizing geographic information systems (GIS), we analyze and visualize population density in disaster-affected areas within the GBA. This spatial analysis helps to develop a comprehensive spatial configuration strategy for EDPIC. (3) AHP method: We construct an objective decision-making model to prioritize key design elements and develop a disaster prevention product design strategy based on the green modular concept. This strategy guides the spatial configuration and design of the inflatable cabin. This model helps to develop a disaster prevention product design strategy rooted in the green modular concept. By quantifying user needs and preferences, the AHP method ensures that the design of the inflatable cabin aligns with the practical requirements and expectations of flood refugees. (4) Modular design: The final step involves discussing the mechanical performance of the EDPIC in earthquake-prone regions through numerical simulation. This phase includes performing finite element analysis (FEA) to simulate the structural integrity and performance of the inflatable cabin under various load conditions. The mechanical performance simulation ensures that the design meets safety and durability standards, making the EDPIC a reliable and effective solution for disaster prevention. The insights gained from the simulations are used to refine the design and enhance its resilience in challenging environments.

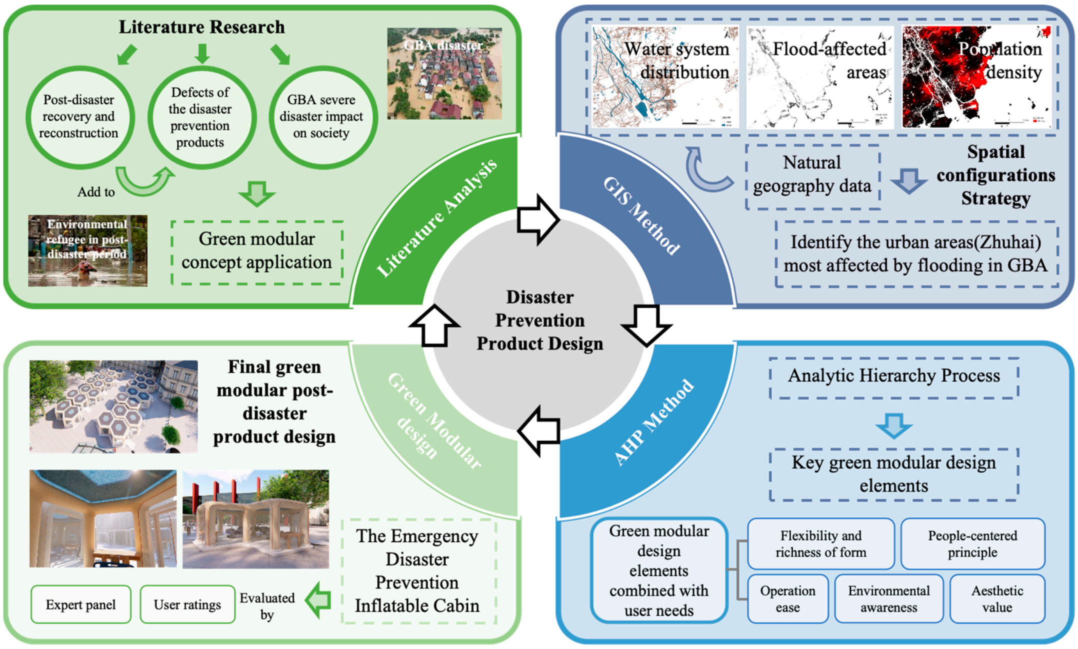

Figure 3. The scientific research steps of this study.

3.1. Geographic Information System

3.1.1. Overview of Geographic Information System Method

The definition of GIS, similar to the discipline of geography, lacks a universally accepted, definitive definition due to its interdisciplinary nature. Over the past decade, GIS has emerged as a critical tool for resource management and urban development. Its capacity to store extensive geographical data and facilitate the retrieval, analysis, modeling, and mapping of such data has been instrumental [29].

3.1.2. Disaster Prevention Geographic Information System

The application of GIS is widespread, particularly in spatial analysis, modeling, visualization, and data processing and management (Figure 4). The following aspects highlight its significance.

(1) Mapping locations: GIS enables the identification and mapping of specific places. GIS facilitates the creation of maps by employing automated mapping techniques, data collection, and analytical tools.
(2) Mapping quantities: To fulfill particular requirements or comprehend relationships between locations, individuals map quantitative aspects, such as identifying areas with the highest and lowest quantities. This approach provides more comprehensive insights than solely mapping feature locations.
(3) Mapping densities: In areas with multiple features, merely mapping the feature locations may not effectively reveal variations in concentration. Through density

mapping, one can employ a consistent areal unit, such as acres or square miles, to quantify the number of features and visualize their distribution.

(4) Finding distances: GIS enables the exploration of activities occurring within a specific radius of a feature.

Figure 4. Disaster prevention geographic information system use process.

For this study, spatial data, including water system distribution, flood-affected locations, and population density in the GBA, are collected. GIS is employed to create visual maps by conducting overlay analysis and comparing these three types of information. The most severely affected areas are identified, representing urban regions prone to flooding. From a macro perspective, this approach determines the locations within the city that require post-disaster disaster prevention products.

Based on the overlay of population data and affected areas, we determined which user groups were most likely to need disaster prevention products. Areas with high population densities and frequent flood occurrences were prioritized. The analysis involved layering maps of water systems, flood zones, and population densities to identify hotspots where the demand for disaster prevention products would be highest. These maps were then used to guide the spatial configuration of resources and the strategic placement of disaster prevention products.

3.2. Analytic Hierarchy Process

3.2.1. Overview of Analytic Hierarchy Process Method

The analytic hierarchy process (AHP) is a valuable and efficient technique for multi-criteria decision-making that enables the systematic analysis and quantification of subjective judgments. The analytic hierarchy process is a practical and effective multi-criterion decision-making method for systematically analyzing and quantifying human subjective judgments [30]. This methodology combines qualitative textual subjective descriptions with quantitative numerical objective comparisons, allowing for the systematic analysis of a sample based on mathematical and rational models. Analyzing and deciding complex problems using hierarchical analysis can effectively avoid subjective one-sidedness in demand transformation.

3.2.2. Green Modular Analytic Hierarchy Process

The factors necessary for achieving green modular design are complex and diverse, making hierarchical analysis suitable for comparative analysis of multiple factors under complex conditions. To obtain accurate user needs, the green modular analytic hierarchy process (AHP) (Figure 5) was applied to conduct qualitative and quantitative research and analysis on the target group. This methodology explored the core pain points and disaster prevention needs of Zhuhai flood refugees, analyzed important factors, calculated the weight values of the influencing factors, and arranged the results in order from highest to lowest to produce scientifically sound results.

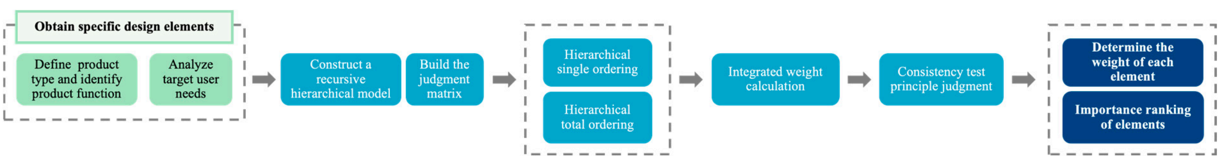

Figure 5. Green modular analytic hierarchy process use process.

3.3. Research Step Analysis

This study integrates GIS and AHP to design green modular disaster prevention products. GIS was employed to gather and analyze spatial data, including water system distribution, flood-affected areas, and population density in the Greater Bay Area, sourced from government databases and satellite imagery. Using ArcGIS, we identified high-risk zones and optimized resource allocation. For the AHP, we selected criteria such as cost, durability, and environmental impact through literature reviews and expert consultations. User needs were assessed via surveys and interviews with a diverse sample of residents from flood-prone areas. We constructed a hierarchical model and performed pairwise comparisons to calculate priority weights, ensuring consistency with ratio checks. This combined GIS and AHP analysis provided a robust framework for designing effective and user-centered disaster prevention products (refer to Figure 6):

(1) Collection of spatial data: Spatial data, including water system distribution, flood-affected locations, and population density in the GBA, are collected and imported into the geographic information system to generate digital visual maps.
(2) Identification of highly affected urban areas: Through the analysis of the visual maps, the urban areas within GBA megacities that are most vulnerable to flooding are identified. Based on the natural geography of these areas, a spatial configuration strategy for disaster prevention products is formulated.
(3) User needs exploration: Quantitative and qualitative research is conducted on the target groups, involving user interviews and questionnaires. The research aims to understand the requirements and expectations of flood refugees in Zhuhai in terms of the products' post-disaster recovery and reconstruction functionalities.
(4) In-depth analysis of research results: The research findings are thoroughly examined to uncover the target group's implicit needs and underlying motivations. This analysis helps to refine and translate the identified needs into specific design requirements.
(5) Qualitative analysis of design requirements: User requirements are further classified and summarized, leading to a qualitative analysis of design requirements. Design elements and directions are determined based on this analysis.
(6) Hierarchical modeling and quantification: The hierarchical analysis method transforms user requirements into a recursive hierarchical structure model. The design elements are quantified using appropriate mathematical methods, clarifying the design objectives.
(7) Weight determination and analysis: The total weight values of all design elements are computed and sorted. Each design element is thoroughly analyzed and understood, leading to the selection of the most appropriate design solution.
(8) Numerical simulation and professional evaluation: In the objective quantitative aspect, numerical simulations are conducted to examine the mechanical performance of EDPIC in earthquake-prone regions. In the subjective qualitative aspect, the scientific validity of the solution is verified through expert scoring and user feedback evaluation after using the product.

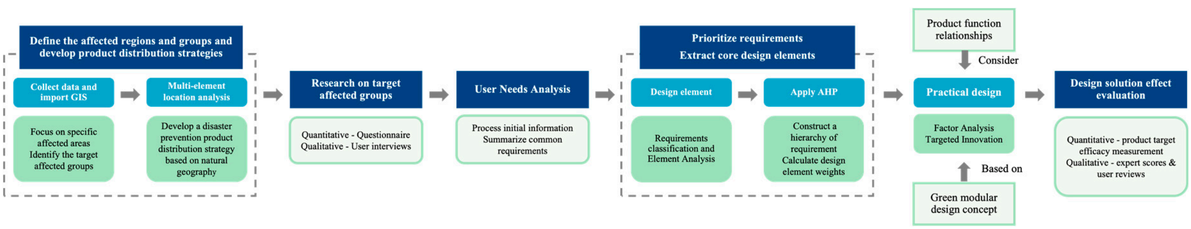

Figure 6. The design flow chart of the green module-based disaster prevention products with AHP-GIS analysis.

4. Research Process and Data Analysis

4.1. Natural Geography Data Analysis

4.1.1. Data Analysis Based on GIS

(1) Water system distribution

A geographic information system (GIS) is utilized to create detailed maps that visually represent various quantities. In the context of the GBA, data on the water system's distribution are collected. Given the geographical location of the GBA within the Pearl River Delta (PRD), it is characterized by a dense river network. The delta's water system is notable for the convergence of three major rivers and the divergence of eight rivers, making it a prominent feature of the region.

Specifically, the Lingdingyang estuary is formed by the Humen Waterway, Jiaomen Waterway, Hongqimen Waterway, and Hengmen Waterway in the east. The Modao Gate estuary comprises the Modao Gate Waterway and Jicimen Waterway in the south. The Hutiaomen Waterway and Yamen Waterway constitute the Yamen estuary. Moreover, the distribution of the river network extends across each city in the area (Figure 7), allowing for the identification of urban areas susceptible to flooding based on the location of the water system distribution.

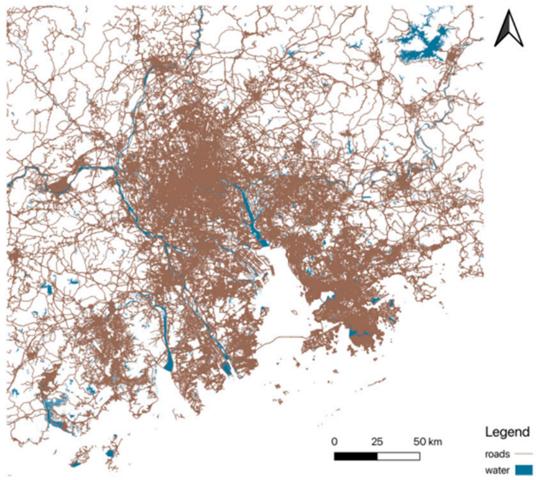

Figure 7. Water system distribution in the GBA.

(2) Population density

The geographic information system (GIS) maps population densities within the PRD. The PRD stands out as one of China's most highly populated regions, characterized by rapid commercialization and urbanization. It is recognized as one of the most densely populated areas worldwide. The visual representation (refer to Figure 8) clearly illustrates the concentration of the population in urban areas. The urban regions exhibit relatively high population densities, indicating that many flood refugees will likely be found there.

(3) Flood-affected areas

The geographic information system (GIS) helps to visualize and explain both the hydro-geomorphic (trenches along barrier beaches, erosion, deposition, etc.) and hydraulic (urban streams along the streets, flow directions, flood extent) factors in the GBA. It also facilitates better highlighting of the affected areas.

The GBA experiences a subtropical marine monsoon climate, resulting in an uneven rainfall distribution, with an average annual precipitation ranging from 1600 to 2300 mm [31]. Consequently, extreme precipitation events have increased, leading to a higher risk of flooding in the GBA (Figure 9). The figure illustrates that areas affected by flood disasters are predominantly located along the coast or in regions traversed by river networks. The varying distribution of these locations also influences the severity and duration of the disasters. Flooding can sometimes extend up to 43 days, inflicting significant damage across affected areas.

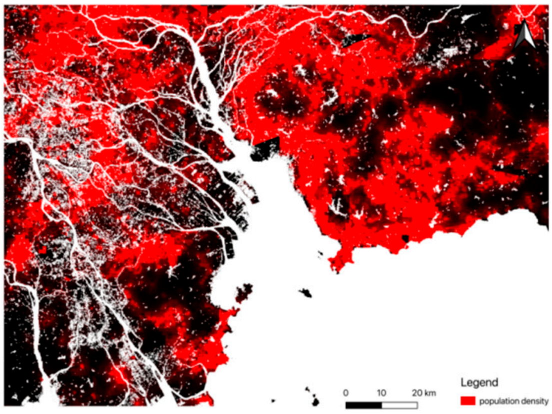

Figure 8. Population density of the GBA.

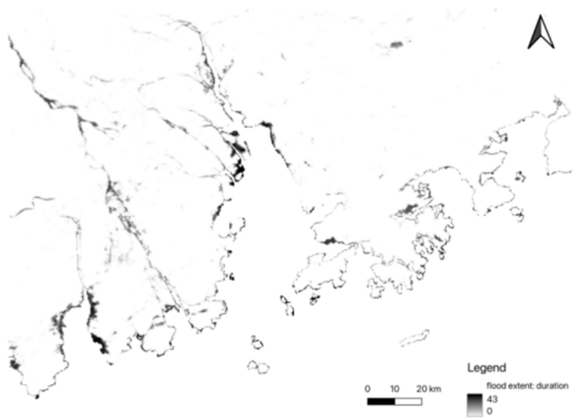

Figure 9. Flood-affected areas of the GBA.

4.1.2. Study Area and Spatial Configuration Strategy Development

After analyzing the combined data on water system distribution, population density, and flood extent in the GBA, it was observed that Zhuhai, among the megacities in the GBA, exhibits a significant vulnerability to flood disasters. Consequently, this study selects Zhuhai as the study area to focus on the implementation of disaster prevention products in this region.

Zhuhai is located between 113°03′ and 114°19′ east longitude and 21°48′ and 22°27′ north latitude. It consists of three administrative districts—Xiangzhou, Doumen, and Jinwan—with a total land area of 1736.45 km^2 as of 2020. Zhuhai City encompasses 15 towns and nine streets. Within the Pearl River Delta, Zhuhai possesses the most significant number of islands, the longest coastline, and the most significant oceanic area. According to the seventh national census, the population of Zhuhai City reached 2.44 million by the end of 2020. The region experiences an average of four typhoons annually from June to October, and torrential rains occur approximately five times yearly. On average, one of these disasters severely impacts Zhuhai City [32]. The Xiangzhou, Doumen, and Jinwan districts, undergoing extensive urban development and infrastructure construction, are particularly susceptible to flood disasters, with significant impacts on the natural and social systems. The recovery process following a flood disaster is protracted, and many flood refugees emerge due to the need to evacuate from flood-affected areas.

Considering these factors, Zhuhai serves as a suitable case study for implementing effective disaster prevention products in response to its vulnerability to flood disasters and the significant population of flood refugees it experiences.

4.2. User Research and Needs Analysis

Utilizing the analytic hierarchy process (AHP), this study focuses on comprehensively understanding the specific requirements of the target user group, namely flood refugees in Zhuhai. To achieve this, an analysis and research were conducted to gain insights into their needs. Through a combination of quantitative research using questionnaires and qualitative research through user interviews (Figure 10), this research aimed to delve into the challenges associated with post-disaster recovery and reconstruction. By doing so, we identify the core pain points experienced by flood refugees and analyze the factors that hold relatively significant influence.

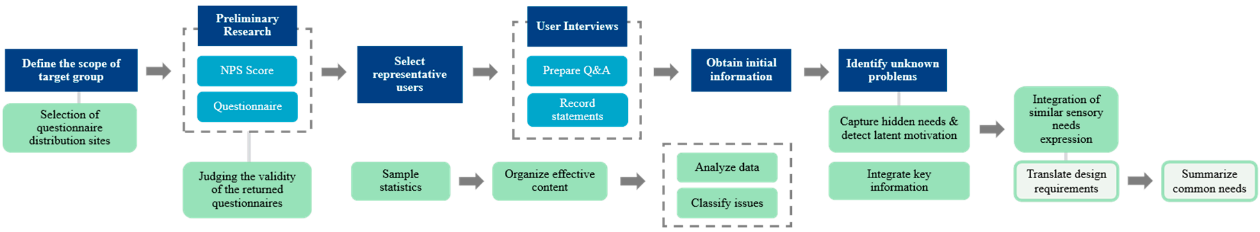

Figure 10. User research and modular design requirement analysis flow chart.

4.2.1. Preliminary Research

To assess the satisfaction of the target group and gain insights into the existing disaster prevention products, this research employed the net promoter score (NPS) and a carefully designed questionnaire. This facilitated the exploration various aspects, including product types, styles, and performance.

A targeted approach was adopted to ensure the accuracy and reliability of the interviews. Specifically, 100 questionnaires were distributed in specific locations known for their vulnerability to flood disasters: Lovers' North Road in Xiangzhou District, the waterway of Maodaomen in Doumen District, and Middle Road and South Road in Jinwan District, all of which were heavily impacted by floods. These efforts collected 82, 68, and 66 valid questionnaires in Xiangzhou, Doumen, and Jinwan Districts, respectively.

4.2.2. User Interview

In order to gather comprehensive insights into the target group's needs, thirty flood refugees in Zhuhai, selected as representative users from the preliminary research, were engaged in in-depth user interviews. These interviews were conducted to record the interviewees' perspectives and capture valuable preliminary information regarding their requirements. The objective was to uncover hidden needs, identify potential motivations, and address previously unknown issues. The information obtained from these interviews is a foundation for the designer to develop a deeper understanding of the target group's requirements.

4.2.3. Analysis of Research Results

The results obtained from the net promoter score assessment indicate that the target group exhibits lower levels of satisfaction with the current market situation of disaster prevention products. Significantly, more than three-quarters of the respondents expressed high expectations for disaster prevention products that specifically address post-disaster recovery and reconstruction. Furthermore, 91.2% of the respondents expressed their desire to integrate the green modular concept into disaster prevention products.

These findings highlight the importance of developing innovative solutions that effectively address the needs and expectations of the target group. The integration of green modular concepts holds particular significance, as it aligns with the preferences expressed by most respondents, indicating a strong desire for sustainable and environmentally friendly approaches to disaster prevention.

In response to these user insights, the present research explicitly connects user needs to the final product design by employing the analytic hierarchy process (AHP). The study systematically quantifies user requirements and prioritizes them based on their importance. This approach ensures that the design recommendations are directly informed by user research findings. The final product design incorporates these prioritized needs, ensuring that the disaster prevention products not only are effective in post-disaster recovery and reconstruction but also align with the concepts favored by the majority of respondents.

4.2.4. Summary of Recognition of Green Modular Concept and Product Design Elements

Through a systematic analysis, the practical information obtained from the questionnaire research and user interviews was carefully categorized, integrated, and refined from a design perspective. Additionally, by considering relevant design elements, the users' potential motivations and ambiguous needs we analyzed, and their language was translated into a concrete overview of user requirements. To facilitate this process, all design elements related to modular design were summarized for each requirement, and a qualitative requirement analysis was performed using an affinity diagram methodology.

Based on this comprehensive analysis, the essential requirements for post-disaster products targeting flood refugees in Zhuhai can be summarized as follows:

(1) Water and moisture resistance: Given the damp environment following a flood, the product must effectively safeguard property and health by protecting against water and moisture.
(2) Safety and stability: The product should exhibit sufficient stability and durability to withstand the potential damage and risks associated with flooding.
(3) Rapid deployment: The ability to swiftly erect and dismantle the products is critical, enabling refugees to adapt to rapidly changing environments and cater to their evolving needs.
(4) Spatial flexibility: The product should offer ample space and flexibility to accommodate the diverse requirements of refugee families and individuals.
(5) Human comfort: The products must create a comfortable, warm, safe, and hygienic environment, prioritizing the physical and psychological well-being of the refugees.
(6) Sustainability: Environmental impact and sustainability considerations are paramount. The products should utilize environmentally friendly materials and energy sources while minimizing waste and pollution.
(7) Ease of transportation and storage: Products should be easily transportable and storable, facilitating rapid deployment and disassembly when needed.

4.3. Primary and Secondary Analysis of Combination of Modular Design Elements and User Needs

4.3.1. Calculation of Design Evaluation Level Index Weights

Based on the findings from the study mentioned above, the prominent indicators for modular design encompass the utilization of environmentally friendly materials, the integration of energy-efficient design features, and the reduction in waste and pollution. Based on these insights, post-disaster products were developed specifically to address the needs of flood refugees in Zhuhai and employ a set of criteria to establish the significance levels of the design elements, presented in Table 1.

The weights of the aforementioned secondary indicators were determined using the expert questionnaire method. The study assumed the participation of L experts and employed the Delphi technique for the questionnaire-based investigation. This process obtained a ranking matrix based on the recorded statistical results.

$$A = (axi)L \times M(x = 1, 2, \ldots, L, i = 1, 2, \ldots, M)$$

Table 1. Evaluation level index of modular design.

	Tier 1 Indicator	Tier 2 Indicator		
Importance of post-disaster product design (U)	U1: Safety and comfort	U11: People-centered principle	U12: Structural stability	U13: Thermal insulation
	U2: Sustainability	U21: Modularization	U22: Life cycle assessment and optimization	U23: Use of renewable energy sources
	U3: Operational practicality	U31: Easy-to-use construction steps	U32: Ease of transportation and storage	U33: Adaptability to different environments
	U4: Aesthetic ornamental	U41: Honeycomb shape and aesthetic ornamental features	U42: Color and texture	U43: Visual harmony with surroundings
	U5: Flexibility and richness of form	U51: Inflatable membrane structure and foldable design	U52: Customizability	U53: Expandability and modularity

Upon acquiring the scores provided by the experts, the entropy theory was applied to calculate the entropy values associated with their evaluations. By leveraging the theoretical foundation mentioned above, the weights of the indicators were calculated, thereby elucidating the significance of the secondary indicators within this study.

Based on the derived weightings, all secondary indicators were categorized into "major impact", "medium impact", or "minor impact" groups. Subsequently, the importance level of each secondary indicator was scored. The final scores for the Tier 1 indicators were then computed by their respective weights, as depicted in Table 2.

Table 2. Secondary indicator score.

Symbol	Secondary Indicator	Scoring Interval	Final Score for Level 1 Indicators
p1	U11: People-centered principle	[90, 100]	
p2	U12: Structural stability	[80, 90]	P
p3	U13: Thermal insulation	[0, 80]	
w1	U21: Modularization	[90, 100]	
w2	U22: Life cycle assessment and optimization	[80, 90]	W
w3	U23: Use of renewable energy sources	[0, 80]	
c1	U31: Easy-to-use construction steps	[90, 100]	
c2	U32: Ease of transportation and storage	[80, 90]	C
c3	U33: Adaptability to different environments	[0, 80]	
m1	U41: Honeycomb shape and aesthetic ornamental features	[90, 100]	
m2	U42: Color and texture	[80, 90]	M
m3	U43: Visual harmony with surroundings	[0, 80]	
n1	U51: Inflatable membrane structure and foldable design	[90, 100]	
n2	U52: Customizability	[80, 90]	N
n3	U52: Expandability and modularity	[0, 80]	

4.3.2. Analysis of Design Elements

The calculation results indicate the following importance arrangement for the design elements: safety and comfort > sustainability > operational practicability > flexibility > aesthetics. These importance rankings should guide the distribution of importance for each design attribute in the subsequent design scheme.

Within the safety and comfort category, the people-centered principle emerges as the most crucial factor, prioritizing the physical and emotional well-being of the refugees. Sustainability emphasizes modularization, encompassing environmentally friendly materials, energy efficiency, and waste and pollution reduction to promote environmental protection and product sustainability. Operational practicality places emphasis on easy-to-use construction steps, quick and effortless assembly and disassembly, and operational feasibility with minimal personnel requirements. The flexibility and richness of form highlight inflatable membrane structures and foldable designs, enabling product flexibility, portability, and adaptability to unique and catastrophic environments. Aesthetic ornamental aspects center on honeycomb shapes and aesthetic design features, emphasizing the visual appeal and morphological richness of the products.

4.4. Green Module-Based Disaster Prevention Design Practice for Flood Refugees in Zhuhai

Using the green modular hierarchy analysis, we ranked the design requirements, leading to developing the final design solution: the emergency disaster prevention inflatable cabin. This design concept, rooted in the principles of modular design, specifically caters to the needs of post-flooding disaster recovery and reconstruction efforts. The design fulfills functional requirements and offers a comfortable and visually appealing environment for flood refugees.

4.4.1. Sustainability

The product design integrates modular design principles, facilitating efficient assembly and disassembly processes that minimize waste generation in the post-disaster phase. In addition, incorporating solar power devices contributes to energy conservation and reduces the carbon footprint. The product is constructed using a lightweight and durable polytetrafluoroethylene (PTFE) membrane structure, which is environmentally friendly and resilient. Figure 11a depicts the flexible top structure of the cabin, designed to effectively mitigate the impact force caused by small gravel during the post-disaster reconstruction period.

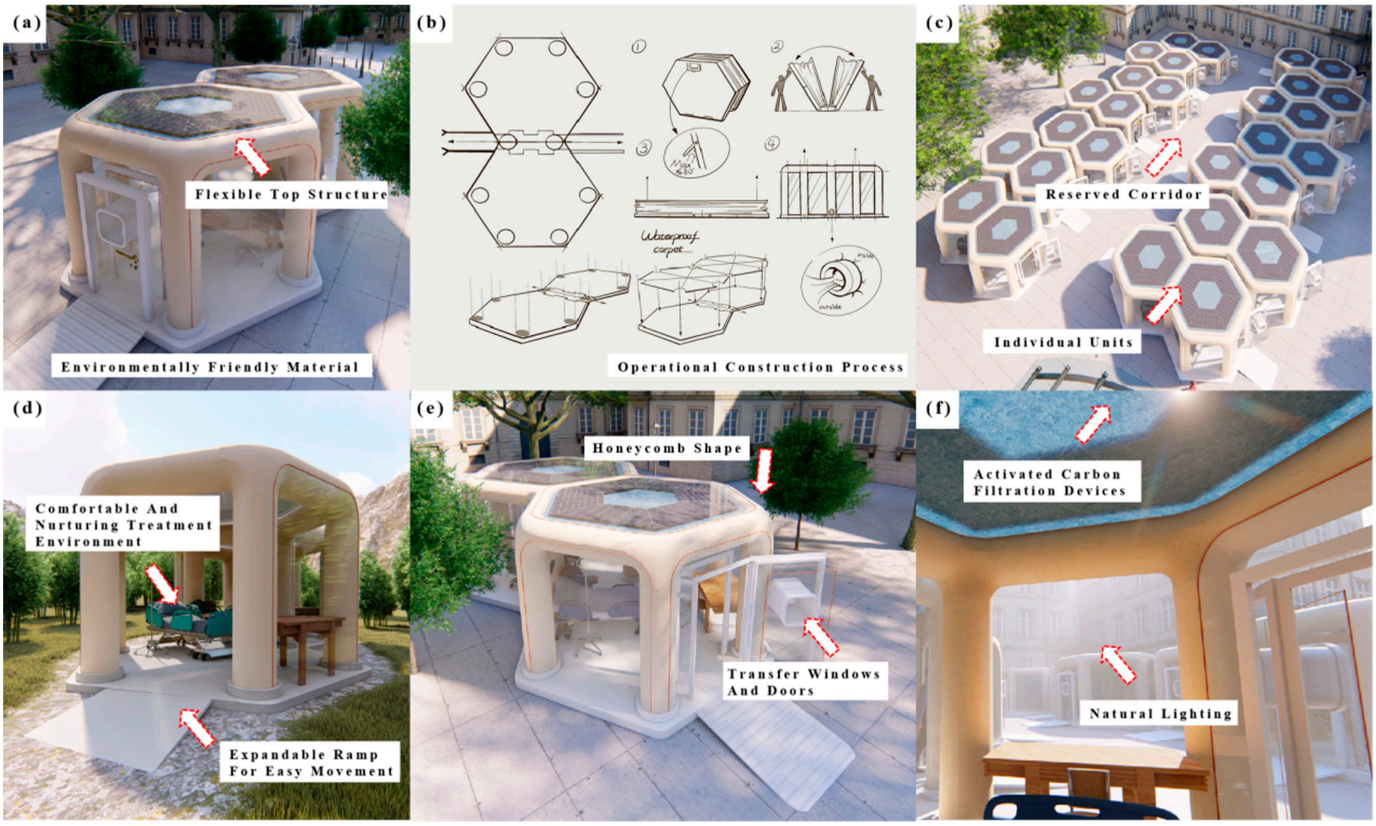

Figure 11. Product performance introduction, (**a**) sustainability, (**b**) operational practicality, (**c**) flexibility of form, (**d**) richness of form, (**e**) aesthetic ornamental, and (**f**) safety and comfort.

4.4.2. Operational Practicality

Regarding operational practicality, the unit body is designed for ease of construction. Just two individuals can build it. The construction process involves pulling the handle of the chassis in the merged state, which opens and closes the hexagonal chassis using a pivot structure. Once the chassis is fully expanded, the lower inflatable port connects to the inflatable device, allowing gas to support the unit's membrane structure. When the gas reaches saturation, the inflatable device is removed, the inflatable port is closed, and the unit is successfully built. To close the unit, the air outlet on the opposite side of the inflatable port is opened to release the gas inside the body. The complete process is illustrated in Figure 11b.

4.4.3. Flexibility and Richness of Form

The disaster prevention cabin adopts an inflatable membrane structure with a foldable design, ensuring its light weight, simplicity, convenience, and ease of storage, transport, and assembly. This design caters to the urgent needs of flood refugees. Figure 11c shows the mass production of individual units, addressing the requirement for large-scale isolation during flood disasters. To mitigate safety risks associated with inflatable structures, such as susceptibility to strong winds, the stability of the base has been meticulously considered. Additionally, the cabin incorporates necessary transfer windows and doors and an expandable ramp for the easy movement of beds, which is shown in Figure 11d,e.

4.4.4. Safety and Comfort

The cabin design adheres to the people-centered principle. The interior space planning considers the physical and emotional well-being of the refugees, ensuring a comfortable and nurturing treatment environment. Figure 11f shows that the cabin incorporates considerations for natural lighting, ergonomic principles, and activated carbon filtration devices located on the top to maintain a clean and healthy environment. Given the centralized application scenario of the product, the reserved corridor design acts as a buffer zone, enhancing the safety of medical staff, which is shown as Figure 11c.

4.4.5. Aesthetic Ornamental Aspects

Furthermore, Figure 11e shows that the cabin's honeycomb shape and aesthetic ornamental features contribute to its form's flexibility and richness, making it both functional and visually appealing.

4.4.6. Summary of Design

Post-disaster emergency products, as a branch of disaster prevention products, need to meet both shelter and protection requirements. Common secondary impacts of natural disasters include injuries and destruction caused by falling debris in seismic events, as well as inundation and erosion resulting from floods, which is shown in Figure 12a–c. Our products are designed to address the secondary hazards associated with these two types of disasters. As depicted in Figure 12d, the protective shelters used in this study feature an inflatable layer that envelops the outer shell. This design effectively dissipates the impact energy of small falling rocks, reducing their potential to cause harm, which is shown in Figure 12f. Traditional tents, on the other hand, lack this capability and are more susceptible to damage from falling rocks, leading to secondary harm to people and property, which is shown in Figure 12e. Additionally, the independent inflatable structure of these shelters can effectively prevent immersion in floodwaters and can float on the water's surface, serving as temporary kayaks with strong protective capabilities against the secondary hazards of floods.

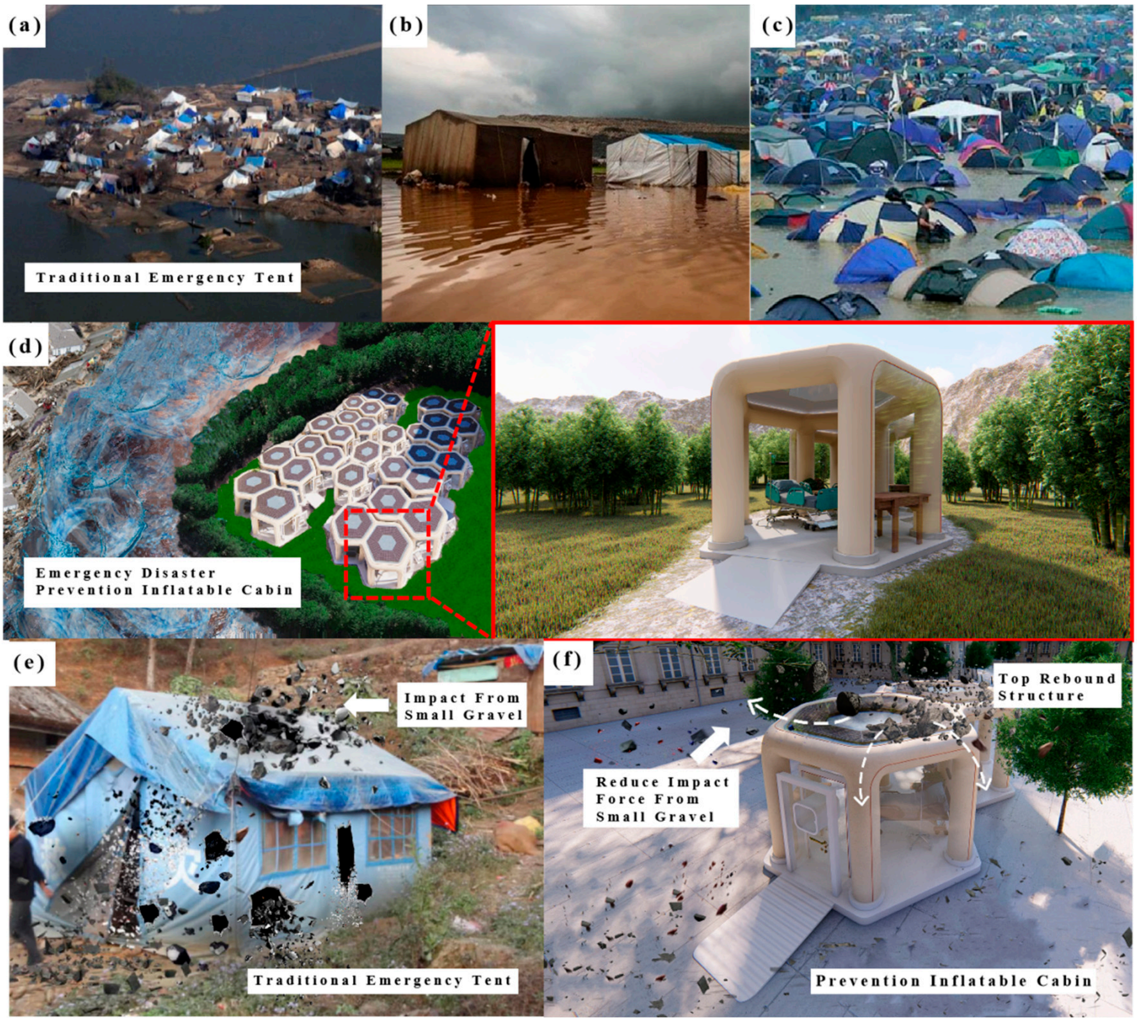

Figure 12. A comparison of traditional emergency tents and the disaster prevention inflatable cabin. (**a**–**c**) Different types of traditional emergency tents. (**d**) The emergency disaster prevention inflatable cabin. (**e**) Traditional tents face significant impact from small rubble. (**f**) Optimized roof elastic structure to effectively mitigate the impact of small gravel.

4.5. Design Evaluation Processes

4.5.1. Expert Panel

To ascertain the fulfillment of the target group's needs, a comprehensive evaluation and user feedback test were conducted as part of the modular design process for the disaster prevention product. A panel of twenty experts from design, materials, and relevant fields was assembled to evaluate whether the design objectives were achieved. The evaluation employed a seven-point scale as the scoring criteria, with the horizontal axis representing the evaluation metric and the vertical axis indicating the corresponding scores.

The scoring criteria were as follows:

(1) Functionality: The extent to which the product performs its intended function effectively.
(2) Usability: The ease of use and user-friendliness of the product.
(3) Durability: The product's ability to withstand environmental conditions and wear over time.
(4) Safety: The degree to which the product ensures the safety of its users.
(5) Aesthetics: The visual appeal and design quality of the product.
(6) Sustainability: The environmental impact and use of sustainable materials in the product's design.

(7) Cost-effectiveness: The balance between the product's cost and its overall value and performance.

Each criterion was scored on a scale from 1 to 7, where 1 indicated poor performance and 7 indicated excellent performance. The scoring system demonstrated a positive correlation between the score and the degree of meeting user needs. This evaluation aimed to provide a professional assessment of the design's effectiveness and alignment with the intended user requirements (Figure 13).

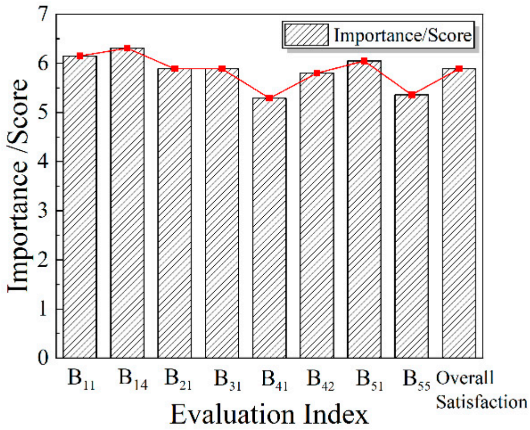

Figure 13. The evaluated result of the expert panel.

4.5.2. User Ratings

In order to gauge user satisfaction with the proposed solution product, we conducted a survey involving thirty individuals who had previously interacted with the design. The net promoter score (NPS) was utilized as a scoring criterion, with the horizontal axis representing the scores and the vertical axis indicating the number of respondents. It is important to note that a positive correlation exists between the respondents' NPS values and their satisfaction and loyalty toward the product (Figure 14). The cumulative NPS score of 48.9 reflects a high level of alignment with the target users' needs, underscoring the design solution's success. This positive outcome further reinforces the viability and effectiveness of the proposed design in meeting user expectations.

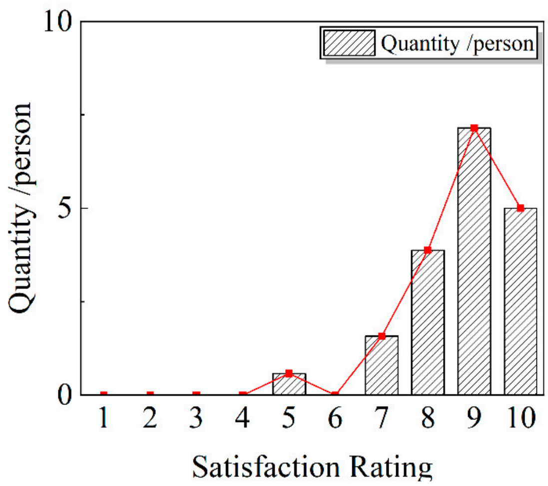

Figure 14. User NPS rating results.

5. Discussion

5.1. Analysis of Application Scenarios and Engineering Mechanical Characteristics

The mechanical performance of the EDPIC holds immense significance during design. Specifically, a critical scenario arises following an earthquake event in regions prone to seismic activities. In this scenario, residential buildings may collapse, necessitating the relocation of residents to emergency tents. However, secondary hazards, such as debris flows induced by rainfall, can cause severe damage to these temporary shelters. Due to precipitation in gullies or slopes, debris flows involve the transportation of substantial solid materials, including mud, rocks, and boulders. The impact forces exerted by debris flows surpass those of floods by a considerable margin.

Consequently, the lack of impact resistance in emergency tents, typically constructed from non-woven fabrics, becomes a pressing concern. In order to address this issue, substituting emergency tents with robust and impact-resistant EDPICs becomes imperative in these application scenarios. This strategic replacement ensures enhanced safety and protection for residents in areas susceptible to seismic activities and subsequent hazards like debris flows. (Figure 15).

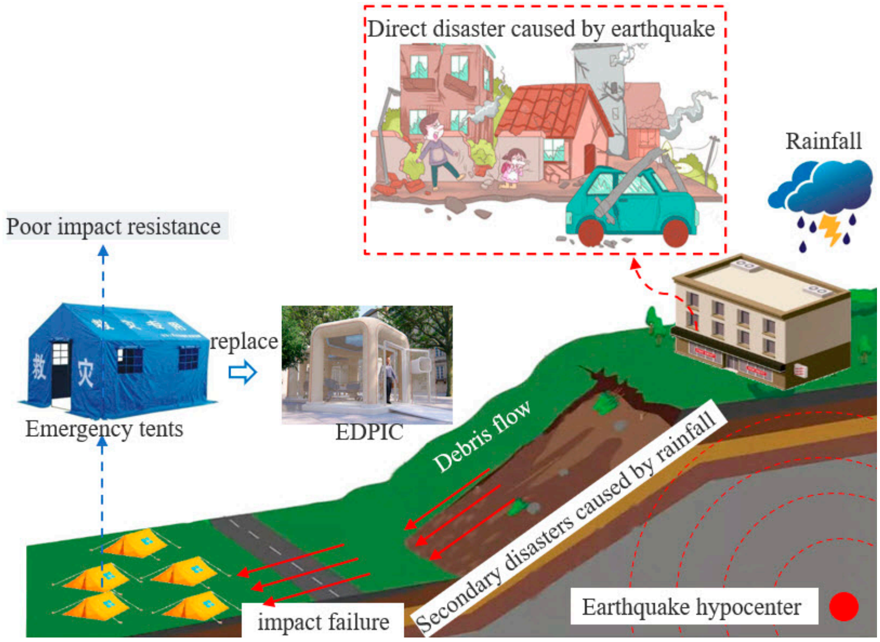

Figure 15. Application scenarios of EDPIC for debris flow protection.

As illustrated in Figure 16a, this study draws upon the physical model introduced by Bi et al. [33,34]. In this context, H_{PIC} = 100 m, α = 45°, and S_{PIC} varies at intervals of 30 m, 60 m, 90 m, 120 m, and 150 m. The primary focus of this investigation lies in the analysis of the impact force variations on the protective cabin at different distances. Figure 16b depicts the three-dimensional discrete element model established in PFC3D, specifically addressing the mechanical characteristics following debris flow impact on its frontal surface. This model serves as theoretical guidance for the mechanical aspects of EDPIC design. The independent variable examined in this study is the distance of the EDPIC from the base of the slope, referred to as S_{PIC}, ranging from 30 m to 150 m, encompassing varying debris flow impact force patterns on the EDPIC. The granular size distribution and specific parameters for this debris flow are derived from the research findings of Zhou et al. [35] (as shown in Table 3).

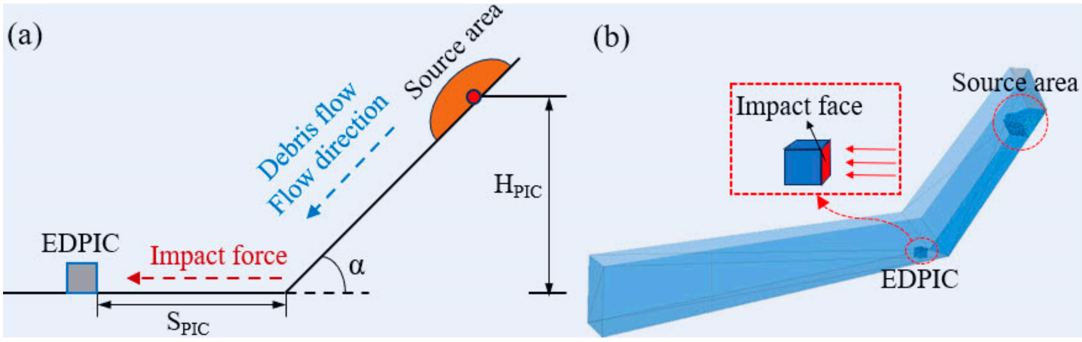

Figure 16. The model for debris flow impact on an EDPIC: (**a**) physical model; (**b**) numerical simulation model.

Table 3. The parameter values for the debris flow in the DEM model.

Parameters	Values
Gravitational acceleration, g (m/s^2)	9.81
Particle density, ρ (kg/m^3)	2650
Normal stiffness coefficient, Kn (N/m)	10^5
Tangential stiffness coefficient, Kt (N/m)	10^5
Interparticle friction coefficient, μ	0.5
Restitution coefficient, e	0.5
Volume fraction, Φ	0.7

According to Figure 17, it is evident that prior to the 70th second, the debris flow velocity exhibits pulsating fluctuations over time. However, after the 70th second, the debris flow velocity displays a gradual decrease over time. Notably, when S_{PIC} = 150 m, the average velocity is relatively low, whereas for S_{PIC} = 30 m, the average velocity is higher, although the difference between them is not substantial.

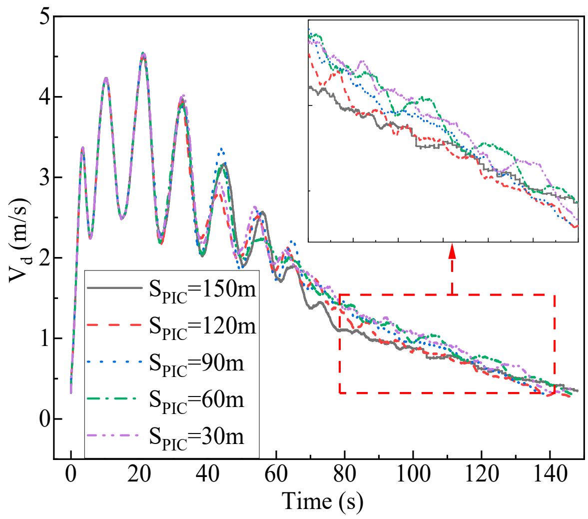

Figure 17. The temporal variation pattern of debris flow velocity.

Figure 18 illustrates the variation in debris flow impact on an EDPIC under different S_{PIC} conditions. As shown in Figure 18a, when S_{PIC} is 30 m, the debris flow exerts a significant impact on the EDPIC, reaching up to 1.8 × 10^7 kN. With increasing S_{PIC}, the impact force gradually decreases. The impact force on the EDPIC generally follows a pattern of increasing with time and eventually stabilizing.

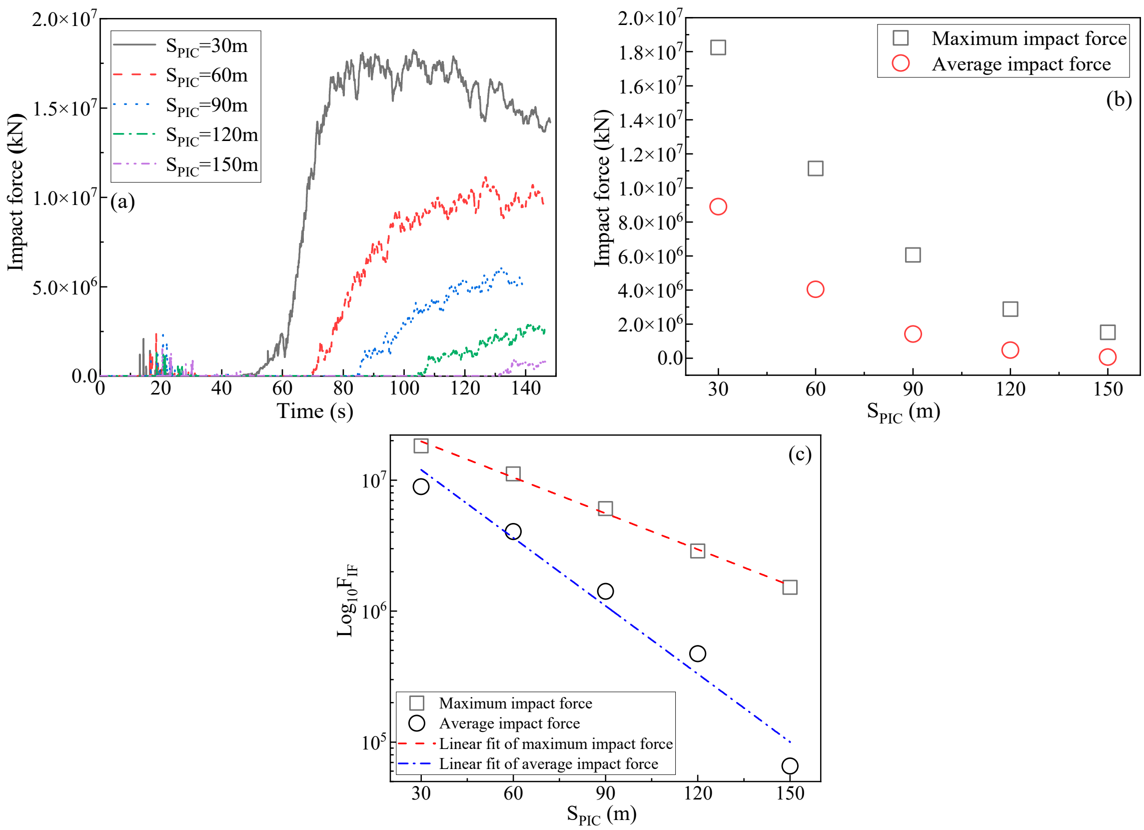

Figure 18. Variations in debris flow impact on an EDPIC: (**a**) temporal evolution of impact force under different S_{PIC} conditions; (**b**) trends in maximum impact force and average impact force with respect to S_{PIC}; (**c**) empirical formulas fitted for maximum impact force and average impact force variation with S_{PIC}.

Figure 18b presents the trends in maximum impact force and average impact force with respect to S_{PIC}. It is evident that as S_{PIC} increases, both the average and maximum impact forces exhibit a gradual decrease. When S_{PIC} increases from 30 m to 150 m, the maximum impact force on the EDPIC decreases by approximately one order of magnitude, while the average impact force decreases by approximately two orders of magnitude.

Figure 18c provides a fitted function for the variation in maximum impact force with S_{PIC}. It reveals that the logarithmic function of impact force is linearly related to S_{PIC}. The specific fitting results are summarized in Table 4. Consequently, this linear relationship allows for the approximate calculation of debris flow impact force based on the position of the EDPIC relative to the slope toe, thereby providing guidance for engineering design.

Table 4. Empirical formulas for calculating maximum impact force and average impact force.

	Maximum Impact Force	**Average Impact Force**
Equation	$y = a + bx$	
Intercept	7.571	7.599
Slope	−0.009	−0.017
COD	0.995	0.968

5.2. Strategies for Disaster Prevention Products and Management at Multiple Levels

This paper develops a comprehensive disaster prevention product strategy by integrating macro, meso, and micro research levels into a unified model. No previous studies have proposed such a holistic approach. Each research level offers distinct advantages, as detailed in Table 5. While most studies focus on examining a single aspect or, at most, combining two, our approach leverages the strengths of all three levels.

Table 5. Analysis of disaster prevention and management at the macro, meso, and micro levels.

Research Level	Specific Performance in Disaster Prevention and Management	Feature
Macro	Measure and assess affected areas	Clarify the importance and scale of the disaster for disaster prevention and planning for recovery and development
Meso	Identify prioritized disaster prevention product design needs	Focus on human and environmental needs, meeting the needs of users, and better following the principles of sustainability in terms of materials, colors, and shapes
Micro	Measure the structural resistance of the product	Functionality is the core of disaster prevention products and is closely related to user safety
Macro–meso–micro	GIS-AHP mixed with numerical simulation analysis	More comprehensive and systemic

In the research on disaster prevention products at a macro level, a geographic information system (GIS) is utilized to create detailed maps that visually represent various quantities. A GIS-based model could be used to characterize the affected areas and interpret both the hydro-geomorphic (trenches along barrier beaches, erosion, deposition, etc.) and hydraulic (urban streams along the streets, flow directions, flood extent) factors.

In the research on disaster prevention products at the meso level, the focus is on identifying and prioritizing the design needs of disaster prevention products. This level emphasizes the importance of understanding human and environmental needs to create products that are both effective and sustainable. Factors such as material selection, color, and shape are considered to ensure the products meet the users' requirements while adhering to sustainability principles.

In the research on disaster prevention products at the micro level, the emphasis is on measuring the structural resistance of the product. The core functionality of disaster prevention products is closely related to user safety, necessitating rigorous testing and the evaluation of structural integrity. This level ensures that the products can withstand the specific conditions they are designed to mitigate, thereby providing reliable protection during disasters.

5.3. Limitations

This research acknowledges several limitations, including potential biases in user feedback, which may arise from the subjective nature of surveys and interviews. Additionally, the research design may have constraints related to the generalizability of findings due to the specific geographic focus on the GBA. To address these limitations, future research could expand the similar geographical environment and include more diverse geographic regions.

Applying the methodologies used in this study involves adapting the GIS and AHP frameworks to local contexts. For instance, spatial data collection should encompass local water systems, flood-prone areas, and population densities relevant to the new region. User needs exploration should involve engaging with local populations through tailored surveys and interviews, ensuring cultural and contextual relevance. In regions with different geographic and socio-economic characteristics, the criteria for AHP may need to be adjusted to reflect local priorities and conditions.

Compared with previous research results, this study confirms an innovative application of disaster prevention products in the post-disaster period. Studies in different geographic areas have also emphasized the necessity of aligning disaster prevention strategies with local needs and conditions. However, this study introduces novel insights into the application of GIS and AHP for optimizing product design and resource allocation, demonstrating that these tools can significantly enhance disaster preparedness and response strategies. These comparisons underscore the effectiveness of integrating spatial data analysis and hierarchical modeling to improve disaster prevention product designs, suggesting that similar approaches can be successfully applied in other regions prone to natural disasters.

6. Conclusions

This study introduces a comprehensive design approach progressing from macro to meso and then to micro levels, as illustrated in Figure 19. At the macro level, GIS analysis is employed to delineate risk zones and formulate product distribution strategies. The meso-level design involves using the AHP method to select and design the basic structure and additional features of post-disaster emergency products. At the micro level, numerical simulations are conducted to assess the impact resistance of product materials.

Figure 19. "Macroscopic—mesoscopic—microscopic" design model.

Guided by the principles of green modularization and sustainable development and driven by core concepts of human care and safety in post-disaster product design, this study utilizes the GIS-AHP design method to explore the post-disaster needs of environmental refugees and devise strategies for emergency product design. Numerical simulations are then used to validate these design strategies. This holistic approach, from a global to a local perspective, holds practical significance for engineering design research.

Addressing the challenges faced by refugees affected by natural disasters is a crucial area of research. Consequently, this study focuses on developing emergency disaster protection products tailored explicitly for flood and inundation scenarios. By employing the AHP method within a GIS analytical framework, the study investigates the requirements of environmental refugees concerning the modular design of disaster products. Through a comprehensive process of user research, demand analysis, weight computations, and detailed analysis, the study identifies user requirements and formulates a product design strategy.

(1) A case study on post-disaster product design for flood refugees in Zhuhai was conducted. Utilizing GIS technology, the most affected areas were identified, leading to

the development of a targeted spatial configuration strategy based on natural geography. This approach improved product efficacy and resulted in a more comprehensive overall strategy.

(2) By prioritizing user demands, the study applied the AHP method to quantify requirements and prioritize user needs, directly translating these into design recommendations. This explicit connection between user research findings and final product design ensured enhanced design efficiency and user satisfaction, with the product's effectiveness verified. The research methodology and process, based on addressing natural disaster issues in the Greater Bay Area and utilizing the GIS-AHP analysis method, provide valuable insights for similar product research endeavors.

(3) Numerical simulations evaluated the protective efficacy of the EDPIC under debris flow impact conditions. As the distance between the EDPIC and the slope angle (S_{PIC}) increased from 30 to 150 m, the maximum impact force significantly decreased, while the average impact force diminished by approximately two orders of magnitude. This analysis resulted in an empirical formula that can serve as a valuable reference for engineering design purposes.

(4) This study presents a novel and integrated approach to designing post-disaster emergency products, combining GIS, AHP, and numerical simulations. Key findings include the identification of effective spatial strategies for product placement, improved design efficiency and user satisfaction through the AHP method, and the validation of product efficacy under diverse conditions. The AHP approach was crucial in quantifying requirements and prioritizing user needs, ensuring a clear connection between user research findings and final product design.

(5) A significant contribution of this study is the development of a comprehensive disaster prevention product strategy by integrating macro, meso, and micro research levels into a unified model. At the macro level, GIS analysis helps identify and prioritize areas most in need of disaster prevention products. At the meso level, the AHP method is used to systematically evaluate and prioritize user needs and design features. At the micro level, numerical simulations provide detailed insights into the material properties and structural performance under various disaster scenarios. This multi-layered approach ensures that the design process is both thorough and adaptable, addressing the complex nature of disaster prevention comprehensively. This holistic approach, which combines spatial analysis, user-centered design, and technical validation, has not been proposed in previous studies on disaster prevention products. By integrating these research levels, the study not only enhances the effectiveness and relevance of the products but also sets a new standard for future research in this field.

Future research will extend this study in several meaningful ways to advance the field of disaster resilience and sustainable design.

First, the approach could be applied to the design of products for other types of natural disasters, such as earthquakes, hurricanes, and wildfires, to assess the generalizability and robustness of the design framework. By adapting the GIS-AHP methodology and numerical simulations to different disaster scenarios, researchers can identify commonalities and unique requirements across various types of emergencies.

Second, further refinement of the empirical models through more extensive field testing and real-world data collection is essential. Enhancing the accuracy and reliability of the design recommendations will ensure that they are applicable in diverse conditions. This could involve longitudinal studies and real-time monitoring of product performance during actual disaster events.

Third, incorporating advanced technologies like machine learning and the Internet of Things (IoT) could provide more dynamic and adaptive design solutions in real-time disaster scenarios. These technologies can enable predictive analytics and automated responses, thereby improving the responsiveness and effectiveness of disaster prevention products.

Fourth, interdisciplinary collaborations with social scientists, environmental experts, and policymakers are crucial. Such collaborations can enrich the design process by ensuring that the products meet broader social and environmental needs. This includes understanding the social dynamics and environmental impacts of disaster prevention strategies, as well as aligning product designs with policy frameworks and regulatory standards.

Additionally, the results of this study have significant implications for possible modifications or adjustments to existing standards or codes. The comprehensive disaster prevention product strategy developed here can inform updates to building codes, safety regulations, and disaster preparedness guidelines, ensuring that they incorporate the latest research findings and technological advancements.

Finally, while this case study focused on flood refugees in Zhuhai, the methodology and findings can be extrapolated to other countries and regions. By adapting the GIS-AHP framework to local contexts and disaster types, researchers and practitioners can develop tailored disaster prevention strategies that address specific regional needs and conditions.

These extensions will not only broaden the applicability of the study's findings but also contribute significantly to the field of disaster resilience and sustainable design. By addressing the identified gaps and incorporating advanced technologies and interdisciplinary insights, future research can enhance the effectiveness and sustainability of disaster prevention products globally.

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Nomenclature

AHP	Analytic hierarchy process
GIS	Geographic information system
GBA	Greater Bay Area
FEMA	Federal Emergency Management Agency
PRD	Pearl River Delta
PTFE	Polytetrafluoroethylene
EDPIC	Emergency disaster prevention inflatable cabin
H_{PIC}	The vertical height of the center of mass of the prevention inflatable cabin from the ground
S_{PIC}	The horizontal distance between the prevention inflatable cabin and the foot of the slope

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