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ESTABLISHING DESIGN CONCEPT FOR A SELF-ACTIVATED MODULAR FLOOD BARRIER SYSTEM

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Abstract— Flooding poses a significant global challenge, resulting in considerable harm to urban infrastructure, property, and human lives. Tackling this issue necessitates the creation of an effective flood barrier system, particularly in urban areas vulnerable to flash floods. This research presents a self-activating modular flood barrier system designed to automatically respond to increases in water levels. The product's development was guided by essential design criteria, which included automatic activation, modularity, stability, adaptability, and cost-effectiveness. A systematic framework was employed to create and assess four design concepts through a weighted scoring matrix that evaluated 12 critical factors. Among the proposed designs, Design D was identified as the most efficient, exhibiting exceptional performance across all established criteria, with notable strengths in flood direction management, durability, and scalability. Enhancements were made to tackle issues such as stability under high water pressure and user-friendliness. The final design integrated several innovative elements, including floating panels for automatic activation, effective water intake channels, and anchoring systems to improve stability. In summary, this study marks a significant progression in flood mitigation technology, offering practical and scalable solutions aimed at safeguarding urban communities from the severe consequences of flooding, thereby promoting both well-being and environmental sustainability.

I. Introduction

Flooding is an increasingly critical global issue, exacerbated by climate change, rapid urbanization, and aging infrastructure. As cities grow and weather patterns become more unpredictable, the frequency and severity of flood events have increased, posing significant risks to communities around the world [1]. Traditional flood barriers, which were an important method in the past, often struggle to cope with today's unpredictable and severe flood events [2]. This article focuses on identifying design criteria for innovative flood barriers that are suitable for urban areas, require minimal human intervention, and not dependent on power sources. By addressing these specific needs, this study aims to develop practical and effective solutions in modern urban environments.

Based on previous findings, traditional flood barriers have several drawbacks. They are usually bulky, difficult to deploy, and not flexible enough to handle different flood situations [3-4]. These barriers often require a lot of time and effort to install, making them impractical for rapid response. For example, sandbags, one of the most common traditional barriers, require a significant amount of manpower and time to deploy effectively [5]. Therefore, there is a clear need for flood barriers that are compact, easy to deploy, and adaptable to various flood levels. Such barriers will not only save time and resources but also improve the overall efficiency of flood response efforts.

Despite recent advances in flood protection technology, significant gaps have been identified. Most existing research has focused on static and semi-permanent structures, with less attention given to the critical need for more dynamic, self-activating systems that can be deployed quickly and adjusted as needed [6-7]. Current solutions lack the flexibility to adapt to changing flood conditions, varying in intensity and duration. This gap highlights the need for innovative designs that can respond autonomously to rising water levels without the need for external power sources or extensive human intervention.

This study aims to fill this gap by developing and evaluating a self-activated modular flood barrier. This innovative design offers flexibility, ease of use and improved performance. The main objectives of this research are to identify and justify the best design criteria for a self-activated modular flood barrier, evaluate several design concepts based on these criteria, and use a weighted matrix score to select the best option. The selected design will then be refined before moving to the prototyping phase. By systematically evaluating various design options, this research aims to ensure that the final product is effective and practical for real-world applications.

By achieving these goals, this paper hopes to add valuable insights to flood mitigation strategies and provide practical solutions for communities at risk of flooding. The results of this study will guide the advancement of flood barrier technology in the future, leading to more resilient and adaptive flood protection systems. Ultimately, this study aims to contribute to the development of flood barriers that can be easily deployed in urban areas, providing reliable protection against the increasing threat of flooding.

II. Design Criteria Framework

A. Establishing the Criteria

In developing a self-activated modular flood barrier, it is crucial to establish a comprehensive set of design criteria that addresses the unique challenges posed by urban flooding.

Table 1: Description of Selected Design Criteria for Self-Activated Modular Flood Barrier

Design Criteria	Description
Automatic Activation Mechanism	Ensures rapid deployment without the need for human intervention, crucial during sudden flood events [8].
Modularity	Allows for easy assembly and disassembly, enabling the barrier to adapt to various locations and flood scenarios [9].
Easy Installation and Setup	Designed for quick and straightforward installation, minimizing the time and labor required, making it practical for emergency situations [9-10].
Safety and Reliability	Ensures the barrier is robust enough to withstand extreme conditions and provide consistent protection without failure [11].
Stability	Maintains stability under various flood conditions, including high water pressure and fast-flowing currents, preventing dislodgement or damage [12].
Floodwater Direction and Control	Capable of not only blocking water but also controlling its direction and flow, managing floodwaters efficiently and reducing the risk of damage to surrounding areas [13].

Adaptability to Urban Environments	Suitable for urban settings where space is limited and infrastructure is dense, integrating seamlessly into the urban landscape [14].
Low Maintenance Requirements	Requires minimal maintenance, reducing the overall cost of ownership and ensuring the barrier remains operational when needed [1],[15].
Portability and Mobility	Portable and easy to transport, allowing for rapid deployment in different locations and quick response to emerging flood threats [11].
Durability	Durable enough to withstand repeated use and exposure to harsh environmental conditions, ensuring long-term effectiveness and reliability [16].
Extendibility and Scalability	Extendable and scalable, allowing the barrier to be expanded or modified as needed to adapt to different flood scenarios and changing conditions [17-18].
Aesthetic and Urban Integration	Aesthetically pleasing and integrates well with the urban environment, ensuring community acceptance and support for the barrier's implementation [19-20].

Based on a thorough review of literature, brainstorming sessions, and discussions with relevant authorities, the following criteria listed in Table 1 have been identified as essential for the design and implementation of effective flood barriers. By adhering to these design criteria, the development of self-activated modular flood barriers can address the critical needs of urban flood protection, providing a practical and effective solution for mitigating flood risks.

B. Relevance to Flood Protection

In the context of flood protection, it is essential to establish a robust framework of design criteria that address both the functional and practical aspects of flood barriers. Table 2 outlines the key design criteria for self-activated modular flood barriers, highlighting their relevance to effective flood protection. Each criterion has been carefully selected based on its ability to enhance the barrier's performance, adaptability, and ease of use in urban environments. By focusing on these criteria, we aim to develop flood barriers that not only provide reliable protection but also integrate seamlessly into the urban landscape, ensuring community acceptance and support. The table below presents a detailed explanation of each criterion, along with its functionality and practicality.

Table 2: Key Design Criteria and Justifications for Urban Flood Barriers

Design Criteria	Functionality	Practicality
Automatic Activation Mechanism	Provides immediate response to rising water levels, reducing reaction time.	Eliminates the need for manual operation, making it suitable for areas with limited human resources.
Modularity	Enhances flexibility and customization for different flood conditions.	Simplifies transportation and storage, making it easier to deploy in diverse environments.
Easy Installation and Setup	Allows for rapid deployment in urgent situations.	Reduces the need for specialized skills or equipment, making it accessible for a wider range of users.
Safety and Reliability	Provides dependable protection during severe flood events.	Reduces the risk of barrier failure, ensuring continuous protection.
Stability	Prevents the barrier from being compromised by strong currents.	Ensures the barrier remains effective throughout the flood event.
Floodwater Direction and Control	Enhances flood management by directing water away from vulnerable areas.	Reduces potential damage to infrastructure and property.
Adaptability to Urban Environments	Fits within the constraints of urban spaces.	Minimizes disruption to daily activities and infrastructure.
Low Maintenance Requirements	Ensures long-term usability with minimal upkeep.	Lowers maintenance costs and resource allocation.
Portability and Mobility	Facilitates quick relocation and deployment.	Enhances readiness and response capabilities in various locations.

Durability	Maintains performance over time despite adverse conditions.	Reduces the need for frequent replacements, saving costs in the long run.
Extendibility and Scalability	Adapts to varying flood magnitudes and conditions.	Provides a versatile solution that can grow with changing needs.
Aesthetic and Urban Integration	Enhances community acceptance and support.	Ensures the barrier does not detract from the urban landscape, promoting smoother implementation.

III. Methodology

A. Conceptual Design Process

The flowchart shown in Figure 1 outlines a systematic process for the conceptual design and development of a self-activated flood barrier, emphasizing iterative refinement and performance optimization. The process begins with defining the problem, where the objectives, constraints, and requirements are established, followed by identifying design criteria to prioritize key features such as self-activation, modularity, and ease of assembly.

Conceptual ideas are then generated and evaluated against these criteria, with a decision point determining whether to proceed or revisit the ideas. Once a suitable concept is identified, it progresses to preliminary design development, including technical drawings and material selection, leading to prototype development. The prototype is subjected to testing and validation against performance metrics, with feedback loops allowing refinement if necessary. Upon meeting performance criteria, the design is finalized and optimized, incorporating testing results and user feedback. The process concludes with documentation and reporting, ensuring all outcomes, analyses, and insights are compiled for presentation, publication, or commercialization.

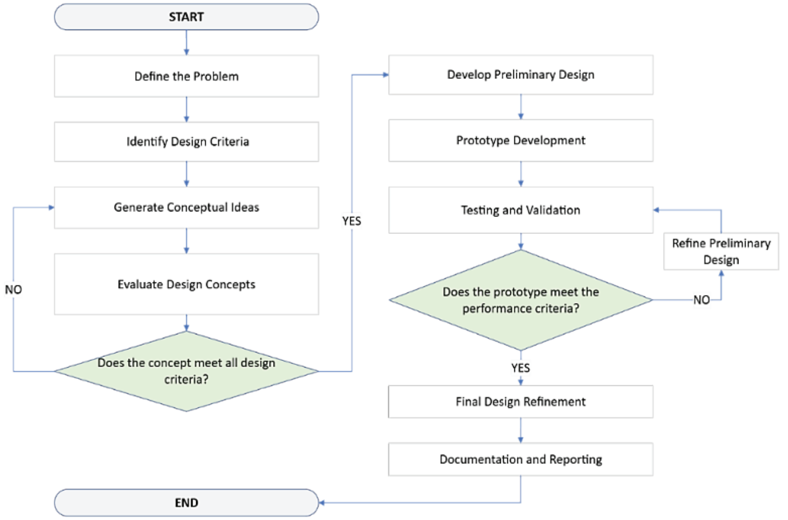


Figure 1: Conceptual Design Phase

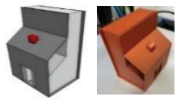
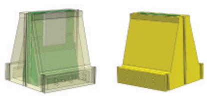
B. Assigned Estimated Weighting

The average weighting for design criteria depends on their perceived importance as derived from literature and expert consensus. Based on typical research priorities and user needs in flood protection systems, approximate weighting is assigned for each criterion, as given in Table 3.

Table 3: Estimated Weights for Self-Activated Modular Flood Barrier Design Criteria

No	Criteria	Weight
1	Automatic Activation Mechanism (AAM)	0.15
2	Modularity (Mod)	0.12
3	Easy Installation and Setup (EIS)	0.08
4	Safety and Reliability (SR)	0.10
5	Stability (Sta)	0.10
6	Floodwater Direction and Control (FDC)	0.06
7	Adaptability to Urban Environments (AUE)	0.06
8	Low Maintenance Requirements (LMR)	0.07
9	Portability and Mobility (PM)	0.05
10	Durability (Dur)	0.10
11	Extendibility and Scalability (ES)	0.05
12	Aesthetic and Urban Integration (AUI)	0.03

Table 4: Multiple Design Concepts Ideas for Self-Activated Flood Barrier based on Design Criteria

Design/Preliminary Modelling	Descriptions	Key Features
Design A: Compact Chamber with Key-slot guide 	This design incorporates a compact modular structure with a dual-section layout, consisting of a vertical back panel and a sloped front face. It features an opening at the base for water interaction. The red slot key is inserted into a designated hole to ensure that the inlet chamber moves upward along a slot or groove when activated.	Compact Design Controlled Activation Scalability Simple Maintenance
Design B: Hinged Flap Canvas with Foldable Frame 	This design utilizes a hinged flap mechanism supported by a foldable frame to form a self-activated flood barrier. The barrier consists of a durable yellow canvas securely held within a collapsible metal or composite frame. When deployed, the hinged flap automatically rises in response to water pressure, allowing the canvas to create an effective flood barrier. The foldable frame ensures the design is compact and portable when not in use.	Compact and Space-Saving Cost-Effective Solution Environmentally Friendly Scalability
Design C: Vertical slim barrier with horizontal inlet water chamber slot 	This design features a vertically slim barrier that integrates seamlessly into a water chamber with a horizontal inlet slot. The vertical barrier is a lightweight, yet sturdy panel placed inside the water chamber. As floodwater enters the chamber through the horizontal inlet, the water level rises, lifting the vertical barrier.	Automatic Activation User-Friendly Installation and Operation Reliable and Durable Adaptability to Flood
Design D: Floating Panel with Water Chamber Activation 	This design consists of a modular unit with a hollow main body that acts as a water chamber. When floodwater enters the chamber through inlet holes, the buoyant floating panel automatically rises, forming a barrier. The side slots allow the units to interlock and form a continuous protective wall.	Self-activation by hydrostatic pressure. Compact storage Quick installation.

C. Designs Screening

The designs screening process for a self-activated modular flood barrier used to identify the most suitable design concept that can be utilized. Multiple design concepts are generated through brainstorming sessions or preliminary modeling, as listed in Table 4. Then, all designs are systematically compared against the criteria using weighted scoring matrix (WSM). Each criterion was assigned a weight (W) based on its importance, ranging from 1 (Poor) to 5 (Excellent). Scores (1 to 5) were assigned to each design concept based on their performance relative to the criteria. The score is then multiplied by the corresponding weight for each criterion, and the total scores are calculated using summation of the weighted scores for each design as given in Equations (1) and (2).

$$\boldsymbol{Weighted\ score} = \boldsymbol{Score}(\boldsymbol{S}) \times \boldsymbol{Weigth}(\boldsymbol{W}) \quad (1)$$

$$\boldsymbol{Weighted\ score} = \sum(\boldsymbol{Score}(\boldsymbol{S}) \times \boldsymbol{Weigth}(\boldsymbol{W}) \quad (2)$$

The alternative with the highest total score is the preferred option. This screening process ensures objectivity, transparency, and alignment with the project's goals, enabling the selection of a concept that best satisfies the established criteria.

D. Evaluation and Design Refinement

After choosing one design as the optimal solution based on the WSM evaluation and team discussion, the next step involves refining the design to address certain weaknesses and enhance its overall performance. The refinement process follows a systematic approach to ensure that the final design meets all project objectives effectively. The refining steps for the selected design are outlined as follows:

- Identifying areas for improvement
- Gathering feedback and insights
- Refining design features

IV. Results and Discussion

A. Evaluation of Design Concepts using WSM

The performance of four design concepts (A, B, C, and D) for the self-activated modular flood barrier system was assessed using a weighted score matrix. The evaluation incorporated 12 criteria that reflect the functional, technical, and aesthetic requirements of the project. The total scores for each design concept are presented in Table 5.

Table 5: Score Distribution for Each Design Concept based on WSM

NO		CRITERIA											
	Weight (W)	0.15	0.12	0.08	0.1	0.1	0.06	0.06	0.07	0.05	0.1	0.05	0.03
	Code	AAM	Mo	EIS	SR	Sta	FDC	AUE	LMR	PM	Dur	ES	AUI
	DESIGN CONCEPT	Automatic Activation Mechanism	Modularity	Easy Installation & Setup	Safety and Reliability	Stability	Floodwater Direction and Control	Adaptability to Urban Environments	Low Maintenance Requirements	Portability and Mobility	Durability	Extendibility and Scalability	Aesthetic & Urban Integration
1	A	3	3	3	4	3	3	3	2	2	4	2	4
2	B	2	2	5	2	2	2	3	4	4	2	2	2
3	C	3	3	3	4	2	4	4	4	2	3	2	3
4	D	4	4	3	4	5	5	4	4	2	5	3	4

The graph in Figure 2 represents the score distribution of four design concepts evaluated across various design criteria using a WSM. Design A demonstrates consistent performance with strengths in safety, reliability, and durability but slightly weaker scores in ease of installation and portability. Design B excels in modularity and aesthetic integration but struggles with floodwater direction and scalability. Design C offers a balanced performance across most criteria, showing notable strengths in stability and low maintenance requirements.

Design D emerges as the strongest contender, particularly excelling in critical aspects such as floodwater direction, durability, and scalability, though it scores lower in portability and adaptability.

Table 6 presents the weighted score results for each design concept evaluated across 12 criteria.

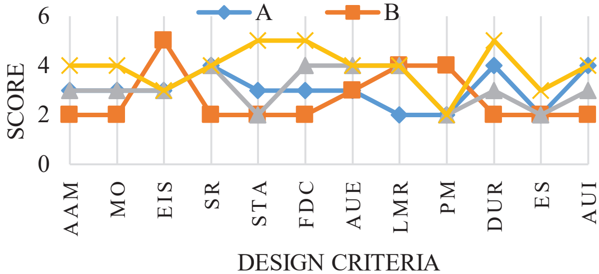


Figure 2: Score Distribution based on Design Criteria for Design Concept A, B, C and D

Table 6: Weighted Score Results for Each Design Concept

DESIGN	CRITERIA												TOTAL SCORE
	AAM	Mod	EIS	SR	Sta	FDC	AUE	LMR	PM	Dur	ES	AUI	
A	0.45	0.36	0.24	0.4	0.3	0.18	0.18	0.14	0.1	0.4	0.1	0.12	2.97
B	0.3	0.24	0.4	0.2	0.2	0.12	0.18	0.28	0.2	0.2	0.1	0.06	2.48
C	0.45	0.36	0.24	0.4	0.2	0.24	0.24	0.28	0.1	0.3	0.1	0.09	3.00
D	0.6	0.48	0.24	0.4	0.5	0.3	0.24	0.28	0.1	0.5	0.15	0.12	3.91

The result can be summarized and evaluated as follows:

- **Design A**: Scored 2.97, performing well in stability and floodwater direction control but lacking in material selection and cost-effectiveness.
- **Design B**: Scored 2.48, indicating generally lower performance across most criteria, particularly in modularity and adaptability to urban environments.
- **Design C**: Achieved a higher score of 3.00, excelling in safety, reliability, and durability but showing weaknesses in cost-effectiveness and portability.
- **Design D**: Achieved the highest score of 3.91, demonstrating consistent performance across all criteria. Notably, it excelled in high-priority areas such as automatic activation

mechanism, modularity, and durability.

The weighted score distribution for design concept shown in Figure 3 indicate that Design D consistently achieving the highest scores in critical criteria such as automatic activation mechanism, stability, durability, and safety and reliability. This highlights its robust functionality and adaptability for flood protection. Design C follows as a competitive alternative with a balanced performance across most criteria, excelling particularly in safety and reliability and low maintenance requirements. In contrast, Design A demonstrates moderate performance, with strengths in automatic activation mechanism and durability but weaker scores in floodwater direction and control and adaptability to urban environments. Design B, however, underperforms significantly in several key areas, including AAM and AUI, making it the least favorable option. Overall, the analysis underscores Design D's superiority, with Design C as a viable secondary option, while Designs A and B require substantial improvements to meet the required standards.

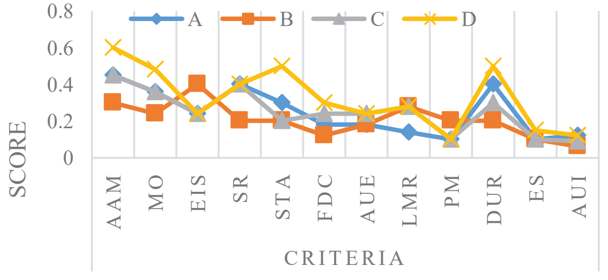


Figure 3: Weighted Score Distribution for Design Concept A, B, C, and D

B. Key Features of the Selected Design Concept

The selected Design D concept for self-activated modular flood barrier system consists of three primary components as shown in Figure 4. The Main Body, Floating Panel, and Connector, are each designed to enhance functionality and performance.

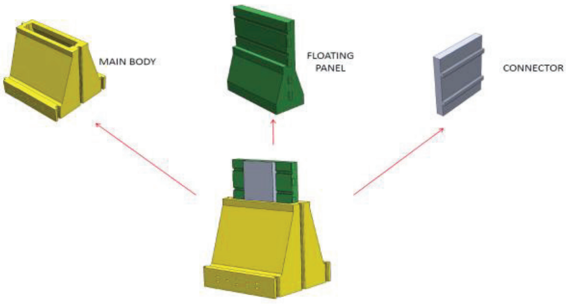


Figure 4: Design D Primary Components for Self-Activated Modular Flood Barrier System

- **Main Body:**

The Main Body serves as the foundation, providing robust structural support to withstand hydraulic forces during flooding. It is also equipped with some holes in the lower section, serving as inlets for floodwater. As water enters, the rising water level within the main body pushes the floating barrier upwards, creating a protective wall against flooding. This feature ensures the system operates efficiently without requiring external power or manual intervention, making it highly reliable during sudden flooding events.

- **Floating Panel:**

The Floating Panel is the key element responsible for the system's self-activation mechanism. Constructed with buoyant materials, it rises automatically with the water level to form a protective barrier. Designed with sliding rails, it ensures smooth vertical movement within the main body.

- **Connector:**

The Connector links individual units, enabling the system to orm a continuous flood protection barrier. Featuring an interlocking design, it ensures a watertight connection between modules while accommodating minor ground-level variations.

V. Conclusion and Recommendations

In conclusion, this study has demonstrated the potential of innovative flood barriers that prioritize modularity, self-activation, ease of transport and assembly, durability, and minimal maintenance. The prototype's performance validated its effectiveness, showcasing reliable self-activation, adaptability through modular design, and cost efficiency. To further enhance the design, it is recommended to conduct large-scale field testing under diverse flood conditions, explore advanced and sustainable materials, and integrate the system with existing infrastructure for a comprehensive flood management approach. Engaging policymakers and local stakeholders is crucial to ensure widespread adoption, while developing design variations for different flood scenarios will enhance versatility.

VI. Acknowledgement

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