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# Design of a Flood Barrier with Developed IoT-Based Flood Detection and Monitoring Systems

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**Abstract:** Due to Indonesia's tropical climate, it experiences frequent heavy rainfall, which is the primary cause of flooding. Despite various solutions implemented, the issue of flooding persists. Consumers demand an effective emergency flood protection solution to prevent water from entering homes at any time. This product is a flood barrier specifically designed for installation at the front door of houses. The development of this flood barrier product aims to address user needs and ensure flood resistance. To achieve this, the Kano method, and Quality Function Deployment (QFD) are utilized in the product design process, aligning it with customer desires. The Finite Element Analysis (FEA) is employed in testing to assess the flood barrier's ability to contain water effectively. Moreover, the data representing the user requirements is collected from residents in the Baleendah area. Those residents' houses have been affected by flooding. This area faces significant economic losses due to flooding, estimated at IDR 5,490,292,000,000. Bandung Regency is projected to have the highest frequency of flooding incidents in West Java in 2022, contributing to the broader issue of flooding in the province and country. The developed flood barrier product has successfully met most customer needs, leading to customer satisfaction. The product offers a reasonable price, customer customization options, and user-friendly features. The integration of Internet of Things (IoT) capabilities has been well-received by users. The flood barrier product also demonstrates its efficacy in retaining floodwater through its low equivalent elastic strain, equivalent stress, and deformation values against hydrostatic pressure. These attributes enable the product to withstand floodwaters and prevent their entry into households.

**Keywords:** Flood, flood barrier, Kano, Quality Function Deployment, Finite Element Analysis, Internet of Things.

## Introduction

Being a tropical country, Indonesia experiences heavy rainfall due to its two distinct seasons. Rainfall, a natural-phenomenon, often leads to flooding [1]. The rainy season in Indonesia spans from November to April, marked by consistently high levels of precipitation over these six months [2]. Throughout the year 2022, there were a total of 1,559 documented cases of flooding across different provinces in Indonesia [3]. Among these, West Java faced the highest number of occurrences, totaling 194 incidents. Notably, West Java held the largest population in the country during the first half of 2022, with a total of 48,637,180 residents [4]. The occurrence of floods can be driven by population density [5]. Waste production is directly proportional to population density [6]. Improper trash disposal by individuals leads to obstructing water flow within drainage systems, thereby increasing the likelihood of water overflow and subsequent flooding [7].

Bandung Regency in West Java Province experiences frequent flooding due to the heightened water volume during the rainy season in three major rivers: the Cisangkuy River, Citanduy River, and Citanduy River [8]. According to Jayantara [8], the household sector in Bandung Regency incurs the most significant economic losses, totaling IDR 11,459,120,778,000, with Baleendah being the sub-regency that suffers the most significant loss, amounting to IDR 5,490,292,000,000. The local government and Balai Besar Wilayah Sungai (BBWS) have implemented a program to address flooding, focusing on the establishment of a Cieunteung Retention Pond in Baleendah Village, operational since 2018, and an Andir Retention Pond in Andir Village, operational since 2021. While retention ponds have yet to offer a permanent solution to flooding, they help mitigate the duration of flood events [9]. An observed flood event on December 17 to 18, 2022, is detailed in Table 1. This flood submerged 2,175 houses in three distinct sub-districts, with water levels ranging from 30 to 60 cm.

**Table 1.** Flood data December 17-18 in Baleendah district

| Location | Number of suffering | | Number of houses flooded |
|---|---|---|---|
| | Householder | Person | |
| Andir Village | 2,224 | 6,524 | 1,967 |
| Baleendah Village | 215 | 519 | 145 |
| Rancamanyar Village | 63 | 186 | 63 |

Given that various solutions have been implemented, the issue of flooding is likely to persist. Household residents must remain vigilant in preparation for potential flooding. Consequently, this research emphasizes creating flood barrier products through instant flood protection doors intended to be installed on entryways, providing a solution for every homeowner. To enhance market appeal, the product's design must cater to user requirements [10]. Furthermore, the designed product must demonstrate its resilience against floodwater.

Users need to know the optimal timing for installing a flood barrier product when a flood event is imminent. As such, the implementation of a flood detection system becomes essential. Through an IoT-based flood detection system, users can receive timely smartphone notifications when a flood is detected. Furthermore, users require information about the floodwater's depth after installing a flood barrier product. An IoT-enabled water level monitoring mechanism aids user in determining hazardous conditions. Consequently, users can proactively prepare and take preventive measures if floodwaters surpass the predefined safety threshold.

## Methods

The design of the flood barrier product is tailored to effectively address inundation scenarios, specifically those arising from intense and sustained rainfall within a confined region over several days. Such flooding incidents stem from limited water absorption capacity, leading to widespread inundation. This research endeavor outlines: first, we identified the customer needs concept design by applying the Kano and QFD methods. Then, we do the finite element analysis and IoT Development.

### Data Collection

Primary data were collected through interviews with residents of Beleendah Village to gather customer feedback regarding the enhancement of flood barrier products, drawing insights from an existing product. The chosen reference product is the QuickDam Floodgate from America, characterized by its instantaneous flood protection door design. Notably, this product is user-installable owing to its "expandable steel jack & frame adjust" feature, permitting adaptable length adjustments to fit door dimensions. Customer statement data is translated into product attributes and processed using the Kano and QFD methodologies. This study employs a questionnaire to categorize product attributes during the Kano stage and ascertain the importance, satisfaction, and expectations of said attributes in the QFD phase. Non-probability sampling, specifically accidental sampling, was employed for questionnaire distribution to samples, resulting in uneven representation across the population. The research population encompassed 145 homeowners who experienced flooding in Baleendah Village on December 17-18, 2022. A sample of 60 individuals was selected utilizing Slovin's Formula [11], with a 10 percent margin of error. Secondary data collection involves seeking information about existing product specifications for reference in the developmental process.

### Data Processing

The data processing stage commences with interpreting customer statements into product attributes. The Kano method plays a crucial role in prioritizing user needs [12]–[14], while the Quality Function Deployment (QFD) method facilitates the identification of factors contributing to heightened user satisfaction [15]–[17]. Within the Kano method, product attributes are categorized as One-dimensional (O), Must-be (M), Attractive (A), Indifferent (I), Questionable (Q), and Reverse (R) [18]. In the subsequent QFD stage, the product attribute categories of Attractive (A), One-dimensional (O), and Must-be (M) are pursued, as other attributes have a relatively minor impact on user satisfaction [19]. The selected product attributes derived from the Kano stages undergo further processing through the QFD framework, which incorporates the House of Quality (HoQ) to define precise product specifications and considerations guiding the development of product concepts [20].

The product concept will be translated into a 3D model, followed by rigorous testing of its robustness using Finite Element Analysis (FEA). FEA serves to determine the threshold values of engineering challenges [21]. The FEA process comprises sequential steps, including geometry modeling, material specification, the division into multiple elements or meshes, application of loading conditions, calculations, and analysis of loading outcomes [22]. Liu *et al.* [23] stated that the deterioration of water barriers in dams or rivers is attributed to hydrostatic pressure, which signifies the force exerted by the depth and density of the liquid. Thus, in this study, loading was simulated in the form of hydrostatic pressure. In line with this, Rahul *et al.* [24] explored the impact of hydrostatic pressure on various aspects, including deformation (alteration in object shape), equivalent elastic strain (comparison of total deformation with the object's initial length), and equivalent stress (resistance of an object to shape alteration), within a similar product, specifically the Self-Operating Flood Barrier at Cochin International Airport.

Additional advancements are underway for flood barrier products, incorporating Internet of Things (IoT) technology for enhanced marketability. These developments encompass an early warning system and a flood monitoring system. IoT is a framework enabling seamless connectivity between humans and computers, obviating the need for direct human-computer interaction [25].

### Analysis with Verification and Validation

The analysis assesses the product's compatibility, considering user needs and its efficacy in water retention. Product verification is executed to ascertain adherence to specifications. The ultimate phase involves presenting the product as a prototype to the relevant stakeholder for validation. Upon completion of the entire research process, comprehensive conclusions will be drawn.

## Results and Discussions

Customer statements were collected from four sources, specifically the heads of neighborhoods whose residences were impacted by flooding in Baleendah Village. The users' responses, constituting raw data, necessitate interpretation into discernible product attributes. It involves articulating needs as actions essential for product performance. The process aims for specificity, employs affirmative sentence structures, and avoids the term "must" to achieve clarity [26]. The interpretation yields ten distinct product attributes meticulously outlined in Table 2. A questionnaire is employed to disseminate these attributes to users, which are then categorized through the application of the Kano Method. Subsequently, each respondent's questionnaire outcomes undergo categorization using the Kano evaluation table, followed by a more in-depth classification of individual product attributes utilizing Blauth's Formula. This formula serves to refine the categorization, reducing attributes that may not be essential or favored by users [27]. The ensuing table presents the outcomes of the product attribute categorization.

Two product attributes must be excluded: "Product has an additional layer of the water repellent (V2)" and "Product has a stopper on the back (V10)". This decision is prompted by their classification as "R" (Reverse) attributes after processing them through Blauth's Formula, indicating user dissatisfaction. The chosen product attributes advance to the QFD stage, wherein each attribute's weight is established. The weighting hinges on user interest, satisfaction, and expectations garnered from a questionnaire, subsequently integrated into the planning matrix [28]. The QFD method facilitates the derivation of precise product specifications [29]. These specifications encompass both technical responses and value components. Product specification values and units can be sourced from competitive benchmarking charts of analogous products and other reference materials. The technical relationship among these responses is identified within the House of Quality (HoQ) through a technical correlation assessment. Here, a double-v ("vv") sign signifies a robust connection, a single-v ("v") sign denotes a connection, and a blank space indicates no correlation.

**Table 2.** Product attribute categorization

| Code | Product attributes | O | A | M | I | R | Q | OAM | IRQ | Category |
|---|---|---|---|---|---|---|---|---|---|---|
| V1 | The product can prevent water | 8 | 4 | 22 | 26 | 0 | 0 | 34 | 26 | Must Be |
| V2 | The product has an additional layer of water repellent | 7 | 1 | 6 | 17 | 29 | 0 | 14 | 46 | Reverse |
| V3 | The product has a strong material | 11 | 3 | 17 | 8 | 21 | 0 | 31 | 29 | Must Be |
| V4 | Products have affordable prices | 16 | 1 | 15 | 13 | 15 | 0 | 32 | 28 | One Dimensional |
| V5 | The product can be adjusted in height | 11 | 1 | 19 | 11 | 18 | 0 | 31 | 29 | Must Be |
| V6 | The product can be adjusted in length | 5 | 0 | 30 | 11 | 14 | 0 | 35 | 25 | Must Be |
| V7 | Products are easy to move | 11 | 4 | 17 | 14 | 14 | 0 | 32 | 28 | Must Be |
| V8 | The product can be used on all types of doors | 7 | 8 | 17 | 12 | 14 | 2 | 32 | 28 | Must Be |
| V9 | Product easy to use | 8 | 3 | 36 | 13 | 0 | 0 | 47 | 13 | Must Be |
| V10 | The product has a stopper on the back | 9 | 3 | 6 | 18 | 24 | 0 | 18 | 42 | Reverse |

Additionally, the HoQ delineates the connection between product attributes and technical responses, categorized as weak, moderate, or strong relationships. These relationships derive a normalized contribution value for each technical response. Figure 1 illustrates the HoQ grounded in product attributes.

The product's width, length, and height collectively contribute positively to its selling price, as higher values correspond to increased pricing. Conversely, the three technical responses oppose the product's mass, as elevated values result in greater product mass, potentially hindering mobility. Water-retaining components, seals, and product installation time favorably influence the product's selling price. The water retention material assumes precedence among these technical responses, boasting the highest normalized contribution value.

Figure 2 depicts the product concept originates from the QFD stages. Comprising three distinct steel plates, each integrates an independent framework to confer water resistance. Notably, the product's width is adjustable, achieved through hydraulic springs that facilitate lateral adjustment by pushing the frame's right and left sections to conform to the door's dimensions. To ensure smooth frame movement, a slider mechanism is incorporated. Moreover, slings and nuts are provided to aid users in restoring the product's length to its original configuration. The integration of strip rubber seals effectively minimizes gaps between the main plate and side plates, while sheet rubber seals seal the sides in conjunction with the bottom of the product. Furthermore, a water stopper seal is strategically positioned to thwart water infiltration at the product's bottom on both the right and left sides.

Loading analysis was conducted using the Ansys 2022 R1 software, employing hydrostatic pressure and a mesh with dimensions of 40 x 40 elements. This analysis's utilization of quadratic elements is attributed to their recognized accuracy [30], [31]. Notably, the density of water was set at 1000 kg/m$^3$. The designated water level corresponds to 60 cm, reflecting the average flood height in Baleendah. The findings reveal that the hydrostatic pressure experienced by the product fluctuates concerning the water level, as depicted in Figure 3. The product's base bears the most substantial pressure, reaching 8,052.3 Pa. The product incorporates a robust structural design to withstand this peak pressure at the base.

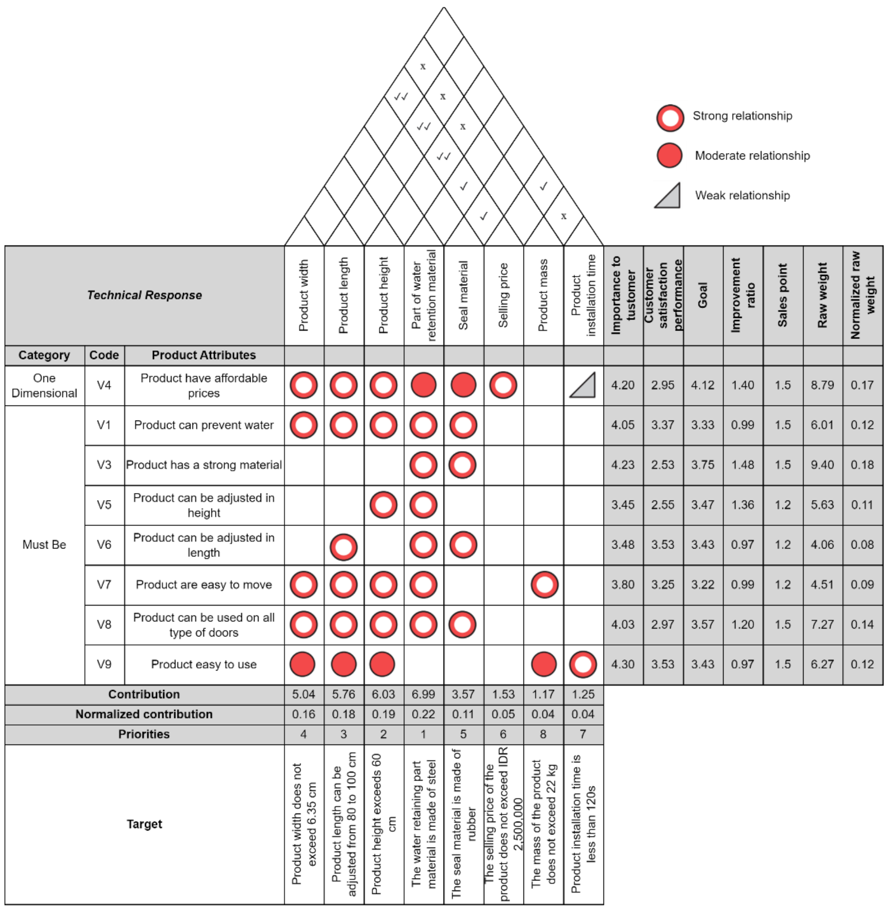


**Figure 1.** House of quality

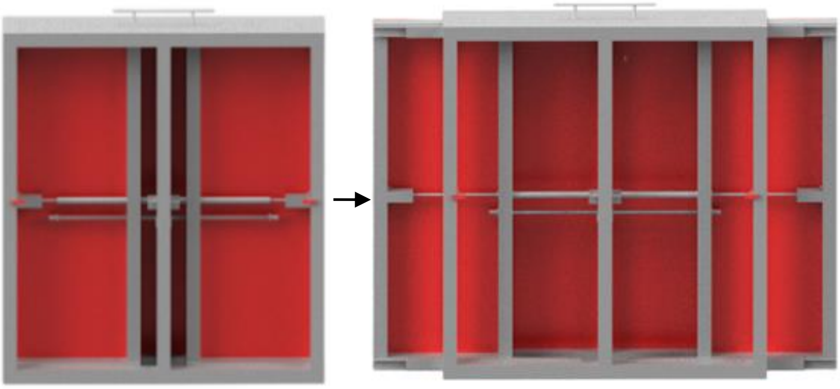

**Figure 2.** 3D Design concept

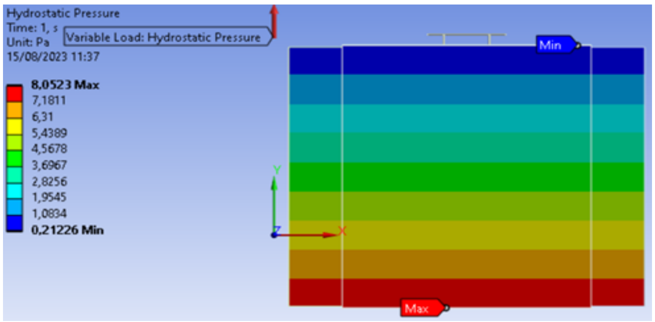


**Figure 3.** Hydrostatic pressure

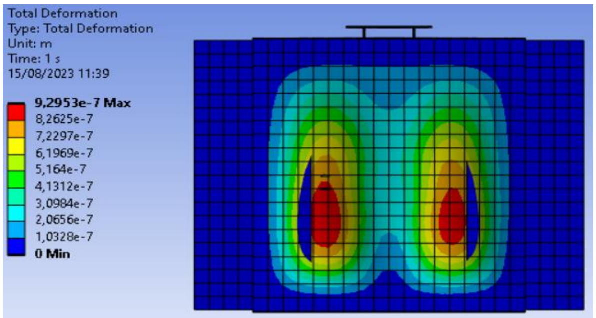


**Figure 4.** Analysis of deformation

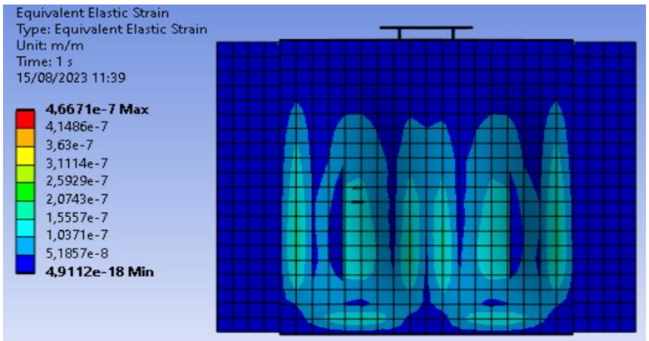


**Figure 5.** Analysis of equivalent elastic strain

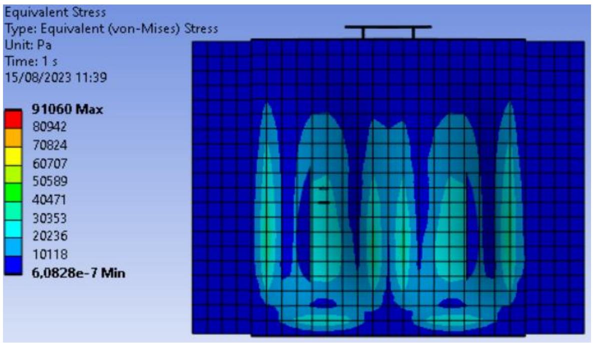


**Figure 6.** Analysis of equivalent stress

Flood barrier products should exhibit minimal deformation, equivalent elastic strain, and equivalent stress values. Total deformation is depicted in Figure 4. where a lower deformation value signifies minimal shape alteration under load. It denotes robust material strength, enabling it to endure substantial loading with limited structural change.

A low equivalent elastic strain signifies heightened material elasticity, facilitating efficient recovery to its initial form even after experiencing significant deformation (as illustrated in Figure 5).

Reduced equivalent stress implies a diminished loading impact on the material, enhancing its resistance and resilience against failure. The outcomes of the product's equivalent stress are illustrated in Figure 6.

Users require information regarding the optimal timing to install a flood barrier product and the likelihood of impending floods. Consequently, a flood detection system becomes imperative. Through an IoT-based flood detection system, users can conveniently receive smartphone notifications when a flood event transpires [32]. In tandem with flood barrier installation, users must also ascertain the flood's height. IoT-enabled water level monitoring media can facilitate the identification of hazardous conditions [33].

An IoT system is incorporated into the flood barrier product as an innovation. Two distinct IoT systems were developed: early warning and flood monitoring. The early warning system employs sensors to detect floodwater, relaying this information to a microcontroller. A water sensor that detects water triggers a buzzer to sound an alarm [34]. An ESP8266 microchip integrated with WiFi technology establishes internet connectivity, serving as a remote-control system [35]. Through microcontroller commands, Whatabot, a messaging service, alerts users via WhatsApp, urging immediate flood barrier installation upon detection. This system necessitates IoT-equipped microcontrollers to establish a hotspot for connection. The flood monitoring system, alternatively, employs ultrasonic sensors capable of converting sound-based physical measurements into electrical values, subsequently translated into accurate distance measurements to gauge water levels [36]. Sensors installed on the flood barrier enable the detection of floodwater levels. While the flood monitoring system's structure closely resembles the early warning system, the distinctive aspect is the platform employed. Blynk is a platform that directly communicates water level information to users. Therefore, the early warning system predicts potential flood occurrences, while the monitoring system gauges floodwater levels. The ensuing block diagram depicts the IoT system configuration (see Figure 7).

The interface connecting the two systems is illustrated in Figure 8 (A) for the early warning system through the WhatsApp application and Figure 8 (B) for the flood monitoring system via the Blynk application.

The intended device's development falls under the mechanical design category[37]. The early warning system can be on the door's wall before flood barrier installation or strategically positioned at potential floodwater detection points, like on a fence. Since the microcontroller should not directly interface with water, it necessitates isolation from the sensor. Conversely, the flood monitoring system will be integrated into the barrier. The mechanical blueprints for both systems are illustrated in Figure 9.

Given users' preference for affordable products, comprehensive calculations are conducted to ascertain the product's selling price. Stonciuviene *et al.* [38] utilized the Full Costing Method, meticulously considering direct, indirect production, and indirect administration costs to determine production expenses. Subsequently, the selling price is derived from the production cost, calculated for a single product produced per day. Table 3

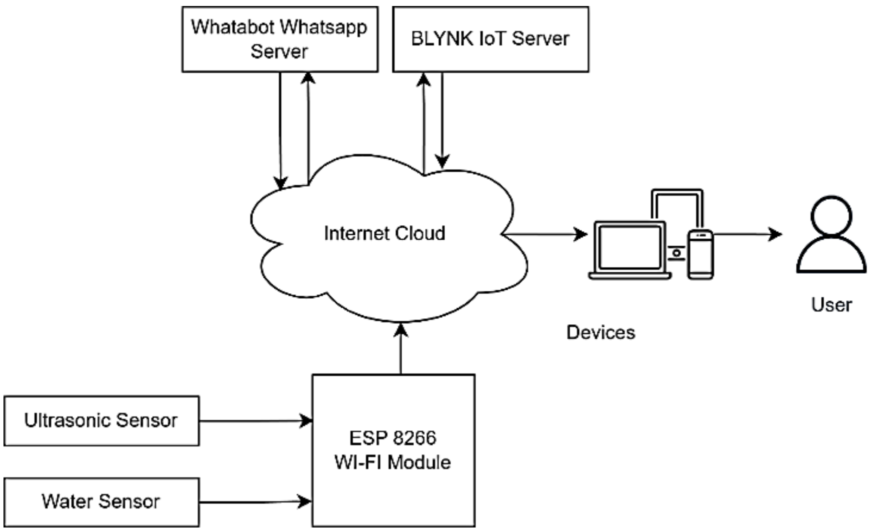


**Figure 7**. Block diagram

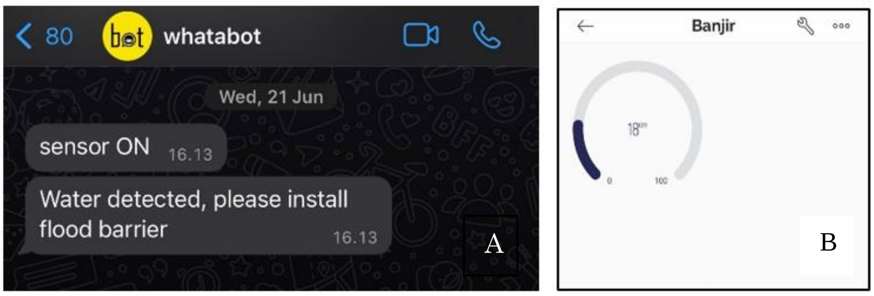


**Figure 8**. (A) Early warning system interface (Whatsapp), (B) Flood monitoring system interface (Blynk)

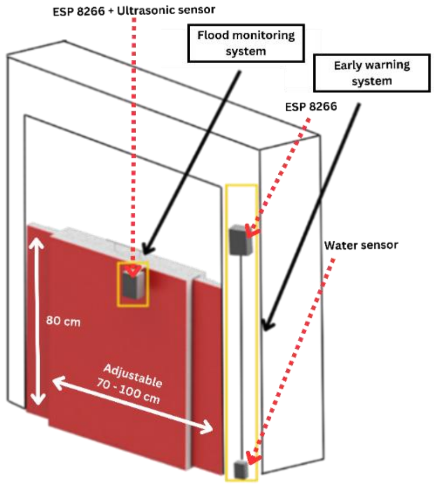


**Figure 9.** Mechanical design

**Table 3.** Cost of production

| Cost | Total cost |
|---|---|
| Material cost | IDR 984,375 |
| Labor cost | IDR 170,000 |
| Fixed overhead cost | IDR 72,270 |
| Variabel overhead cost | IDR 67,060 |
| Cost of production | IDR 1,293,705 |

illustrates the production cost is computed with 312 working days in a year and 26 in a month. The product's selling price will be established through a Cost-Plus Pricing Strategy, which involves adding the desired profit margin to the total production cost [39]. With a desired profit margin of 50%, the resulting selling price amounts to IDR 1,941,000.

After several preceding stages, the final product specifications have been determined. The product possesses a width of 11.5 cm, a height of 80 cm, and a variable length ranging from 70 to 100 cm. The water-retaining element is crafted from steel, while rubber is used for sealing. The designated price for the flood barrier product is IDR 1,941,000. However, two product specifications remain pending: product mass and installation time. Hollow steel, measuring 600 x 3 x 3 cm, weighs 4.52 kg, while hollow steel, measuring 1,036 x 3 x 3 cm, weighs 7.80 kg. The steel plate, measuring 120 x 240 x 0.2 cm, carries a weight of 46.7 kg. An additional steel plate is required, measuring 130 x 80 x 0.2 cm and 140 x 12 x 0.2 cm, contributing a total weight of 19.5 kg. The remaining component adds approximately 0.5 kg. Consequently, the product's total mass equates to 27.8 kg. Notably, owing to the product's key-operated extension mechanism, the installation time is a mere 60 seconds.

Prototype design encompasses both the flood barrier and IoT systems. Prototypes are tangible manifestations employed for assessment by development teams and users alike [40], [41]. The flood barrier prototype measures 12 cm in width, possesses an adjustable length between 70 and 100 cm, and stands at a height of 80 cm. A water-retaining component fashioned from a waterproof MDF wood board is coupled with a rubber seal to construct this prototype. Notably, the water stopper seal has been substituted with aluminum tape. The prototype product weighs in at 20 kg (depicted in Figure 10).

While developing the early warning system prototype, the microcontroller remains integrated with the sensor, while the flood monitoring system retains its specifications without modification. Both the early warning and flood monitoring systems are depicted in Figure 11.

Verification is conducted to ensure adherence to product specifications [42]. Among the six product design outcomes, some align with the intended specifications. The product's length can be adjusted from 80 to 100 cm, a suitable range given that the average maximum flood in Baleendah reaches 60 cm. Thus, the anticipated height of the product is set at 80 cm. The water-retaining component, forged from steel, possesses low deformation, equivalent elastic strain, and elastic stress values, rendering it an optimal choice. Rubber is selected for the seal. The product's price does not exceed IDR 2,500,000, the region's average monthly income.

**Figure 10.** Flood barrier prototype

(A) (B)

**Figure 11. (**A) Early warning system prototype, (B) Flood monitoring system prototype

The product installation time is approximately 60 seconds, facilitated by the product's key-operated extension mechanism, allowing it to adapt to varying door sizes. However, two design aspects deviate from the target specifications. The product's width is 11.5 cm, attributed to the utilization of three hollow steel 3 cm squares arranged linearly for the frame.

Further width is required to accommodate steel plates, hydraulic springs, and long drat components, prohibiting the width from less than 6.35 cm. The hollow steel weighs 7.80 kg, the steel plates contribute 19.5 kg, and an additional component adds approximately 0.5 kg, yielding a total mass of 27.8 kg. Consequently, the product's mass exceeds the targeted specification by 6.8 kg. Based on validation results, users express contentment with the product as it effectively fulfills their needs. The product's affordability, adjustable length, ease of use, and incorporation of IoT features contribute to user satisfaction. Despite the product's inability to reach its maximum intended height, users are still pleased it achieves 80 cm in height. User feedback highlights a concern regarding the seal at the bottom, as water leakage persists. The bottom seal used during validation, substituted with aluminum duct tape from the prototype, deviates from specifications. Users also suggest a reduction in the product's weight.

## Conclusion

The design of a flood barrier product presents a solution suitable for householders residing in flood-prone regions. These products are meticulously crafted to align with user requirements and exhibit commendable efficacy in impeding floodwaters. The formulated product has effectively met user expectations, evident in its capacity to fulfil most of their needs. Offering affordability, length adjustability, and user-friendly operation, the flood barrier product has garnered positive reception. Users express contentment with the supplemental advantages derived from IoT integration. With two user-designed IoT systems, users gain valuable foresight into potential floods, allowing prompt flood barrier installation.

Additionally, users can actively monitor flood situations, enhancing their ability to assess dangerous conditions. Despite the product's inability to be elevated, user satisfaction prevails due to the product's height being appropriately aligned with the area's flood height, which stands at 60 cm. Notably, when confronted with hydrostatic water pressure, the product's minimal equivalent elastic strain, equivalent stress, and deformation values underscore its effectiveness in effectively restraining floodwaters. Within these parameters, the product reliably withstands floodwater and successfully impedes its entry into homes.

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