The Application of Amphibious Structures And Iot-Based Mitigation Systems: Empowering Coastal Communities To Cope With The Threat of Storm Surges On The East Coast North Sumatra Project Location: Belawan Sub-District, Medan Belawan District, Medan City, North Sumatra

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Abstract.
The phenomenon of tidal flooding has become a recurring threat to coastal communities in Belawan Sub-district, Medan City, which forms part of the East Coast of North Sumatra—an area experiencing land subsidence and rising sea levels due to climate change. These conditions have led to damage to settlements, disruption to fishermen's economic activities, and a decline in the environmental health of coastal communities. This community service initiative aims to empower the Belawan community through the implementation of two main approaches: amphibious construction as an adaptive architectural solution enabling floating dwellings to adjust to water level fluctuations; and an Internet of Things (IoT)-based mitigation system comprising water level monitoring sensors and an early warning system linked to a smartphone application. The implementation methods included a socialisation and vulnerability assessment phase, technical training on prototype-scale amphibious construction, installation of IoT devices, community mentoring, and an evaluation of the programme's sustainability. The results of the activities demonstrate an increased understanding amongst the community of adaptive technologies based on local wisdom and appropriate technology, the construction of one prototype amphibious foundation unit at the home of an affected resident, and the functioning of a real-time tidal flood early warning system. It is hoped that this initiative will serve as a replicable model for the empowerment of coastal communities facing the threat of tidal flooding in other coastal areas of North Sumatra.

Keywords: *Amphibious construction; Internet of Things; disaster mitigation; tidal flooding; coastal community empowerment and Belawan.*

I. INTRODUCTION

The Belawan sub-district, situated in the Medan Belawan District of Medan City, is one of the strategic coastal areas on the east coast of North Sumatra, serving as a hub for port activities, fisheries and densely populated settlements. Geographically, this area lies on a low-lying coastal plain with an elevation barely above sea level, making it highly vulnerable to tidal flooding. Over the past decade, the frequency and intensity of tidal flooding in Belawan have shown a significant increase, driven by a combination of factors: rising sea levels due to global climate change; *land subsidence* caused by groundwater extraction and infrastructure loads; and the lack of adequate drainage systems and embankments.

The impact of recurring tidal flooding has caused material and non-material losses for the community, ranging from damage to residential buildings, disruption to the economic activities of fishermen and seafood processing, to an increased risk of disease due to standing water mixed with domestic waste. Conventional, large-scale structural approaches, such as the construction of permanent concrete embankments, require substantial investment and a lengthy implementation period, and are therefore unable to meet the urgent needs of communities at the settlement level. Consequently, an alternative approach is required that is more adaptive, affordable, and can be implemented in a participatory manner by the communities themselves.

Amphibious construction offers a new paradigm in disaster-adaptive architecture, whereby buildings are designed to rise in tandem with rising water levels through a system of floating foundations and vertical guidance posts, without the need to relocate communities from their home villages. This approach has been implemented and proven effective in various countries facing the threat of coastal flooding and tidal surges, and holds great potential for adaptation within the context of traditional fishing communities in Indonesia. Furthermore, developments in *Internet of Things* (IoT) technology present an opportunity for coastal communities to access an early warning system that is cost-effective, easy to operate, and capable of providing alerts before tidal flooding occurs, thereby giving communities sufficient time to take precautionary measures.

Based on the above, this community service initiative has been designed with the following objectives: (1) to enhance the understanding and capacity of the Belawan coastal community regarding the concept of amphibious construction as a housing adaptation solution against tidal flooding; (2) to construct and demonstrate a prototype amphibious foundation system on affected buildings; (3) to design and install an IoT-based mitigation system for monitoring and early warning of tidal flooding; and (4) to promote the sustainability of the programme through the formation of technically self-reliant coastal disaster preparedness groups.

II. THEORETICAL REVIEW

2.1 Amphibious Construction

Amphibious construction is an adaptive architectural approach that allows a building to remain in a fixed position under normal conditions, yet be able to float vertically in response to rising water levels during floods or tidal surges. This system generally comprises three main components: *a buoyant foundation*, which lifts the building structure; vertical *guidance posts*, which keep the building in its horizontal position; and a *flexible utility connection* system for electricity and clean water supplies that can adapt to the building's vertical movement. This approach differs from conventional stilt houses, which remain static at a fixed height, as amphibious construction is dynamic and responsive to water level fluctuations that vary over time.

This concept is also in line with the local wisdom of coastal communities across the archipelago, who have long recognised stilt houses as a form of adaptation to wet environmental conditions; thus, the application of amphibious construction can be viewed as a further development of the vernacular coastal architectural tradition, reinforced by modern engineering principles, without compromising the social and cultural suitability for the local community.

2.2 IoT (*Internet of Things*)-Based Disaster Mitigation System

The Internet of Things (IoT) is a network of physical devices that are interconnected and capable of automatically collecting and exchanging data via the internet. In the context of coastal disaster mitigation, IoT technology can be implemented using ultrasonic *water level sensors* installed at strategic locations, connected to microcontrollers and wireless communication modules, so that water level data can be transmitted in real time to a data centre and relayed as early warning notifications to the public via smartphone applications, sirens or indicator lights. An IoT-based early warning system offers the advantages of relatively low operational costs, ease of installation and the ability to provide continuous monitoring without the need for constant human intervention.

2.3 Empowerment of Coastal Communities and Vulnerability of Tidal Flood-Prone Areas

Community empowerment in the context of coastal disaster mitigation emphasises a participatory process that positions the community as active agents, rather than merely recipients of aid. It is important to apply this principle so that the technologies introduced—whether amphibious structures or IoT systems—can be understood, operated and maintained independently by the community once the community service activities have concluded. The vulnerability of coastal areas such as Belawan to tidal flooding is determined by the interaction between physical factors (land elevation, distance from the shoreline, drainage conditions), socio-economic factors (income levels, settlement density, access to information), and institutional factors (local government capacity and community preparedness); consequently, a comprehensive empowerment approach must integrate technical, social and institutional aspects in a holistic manner.

III. METHODOLOGY FOR IMPLEMENTING THE COMMUNITY SERVICE PROJECT

This community service activity was carried out in Belawan Sub-district, Medan Belawan District, Medan City, using a participatory approach (*participatory action research*) that actively involved the community at every stage of the activity. The implementation of the activity was divided into the following five main stages.

1. Preparation and Vulnerability Assessment Stage. The implementation team carried out a field survey to identify the residential areas most affected by tidal flooding, measured land elevation and tidal patterns, and conducted interviews with community leaders and village officials to map the community's needs and preparedness.
2. Socialisation and Education Phase. *Focus group discussions* and awareness-raising sessions were held for the community on the concept of amphibious construction, the operating principles of IoT systems, and the importance of self-reliant coastal disaster preparedness.
3. Technical Training and Prototype Construction Phase. The community was directly involved in technical training on the construction of prototype-scale floating foundations using recycled plastic drums and lightweight steel frames, as well as the assembly and installation of IoT sensor devices to monitor water levels at flood-prone locations.
4. System Support and Testing Phase. The implementation team provided support for the operation of the early warning system, tested the notification functions during high tide conditions, and conducted response simulations in collaboration with the community and the established disaster preparedness groups.
5. Evaluation and Sustainability Phase. A participatory evaluation of the project's achievements was carried out, along with the drafting *of a* simple maintenance *manual* and the formation of a community cadre group responsible for the continued operation and maintenance of the system following the project's completion.

IV. DISCUSSION

4.1 Technical Feasibility and Performance of the Amphibious Construction Prototype

The implementation of the community service activities demonstrated that the Belawan community has a high level of acceptance of the amphibious construction approach, particularly as this solution does not require them to leave their settlement, which has been their living space and source of livelihood for generations as fishermen. This acceptance is important to note because many coastal settlement relocation programmes in various regions have faced social resistance due to the severing of the community's emotional and economic ties to their area of origin. By offering a solution that preserves the residential location, amphibious construction provides a middle ground between the need for technical adaptation and the socio-cultural sustainability of coastal communities.

A prototype amphibious foundation, constructed on one of the affected residents' homes, was successfully demonstrated to be capable of adapting to rising water levels during a flood simulation of approximately 40 centimetres, indicating the technical feasibility of this approach for further development on a larger settlement scale. The testing was carried out by gradually filling a simulation pool surrounding the foundation with water, then observing the vertical movement of the building structure relative to four guide posts installed at the corners of the foundation. The results of the observations showed that the building structure was able to rise steadily without experiencing significant horizontal displacement, with a displacement tolerance of less than 3 centimetres, which remains within safe limits according to the technical guidelines for amphibious construction applied in previous studies.

The selection of 200-litre recycled plastic drums as *flotation devices* also offers added value in terms of cost-effectiveness and the utilisation of local resources, which are abundant in the Belawan port area.

Each prototype amphibious foundation unit utilises 12 plastic drums arranged within a rust-proof coated lightweight steel frame, with an estimated total buoyancy of over two tonnes—sufficient to support a simple 6 x 8-metre stilt house. This approach to using recycled materials supports the principles of the circular economy whilst reducing reliance on conventional foundation materials, which are far more expensive; consequently, this solution is more realistic for implementation amongst low- to middle-income communities.

Nevertheless, several technical considerations were identified that require attention in future development, including the need for regular maintenance of the lightweight steel frame joints—which are susceptible to corrosion due to continuous exposure to brackish water—as well as the need for more in-depth structural analysis should this approach be applied to permanent multi-storey buildings. The implementation team recommends the use of an additional protective coating (*hot-dip galvanised coating*) on the metal frame elements, as well as regular inspections every six months as part of standard maintenance procedures, which need to be communicated to community leaders.

The community service team, whilst conducting observations in the Belawan coastal area, visited the site in person and met with local residents.

Fig. 1. Photograph of the team carrying out observations in the Belawan coastal area

4.2 Effectiveness of the IoT-Based Mitigation System

Regarding the IoT-based mitigation system, the installation of ultrasonic water level sensors at three strategic points—namely, the mouth of a small river, a densely populated residential area, and a fishing pier—successfully transmitted data in real time and provided early warning notifications to the disaster response team via a smartphone application, with an average delay of less than one minute from the time the data was read by the sensor until the notification was received by the user. The system is designed with three warning thresholds: an ‘alert’ status at a water level of 10 centimetres, a ‘caution’ status at 25 centimetres, and a ‘danger’ status at 40 centimetres, each accompanied by a different indicator colour on the app and on physical signal lights installed at community watch posts.

Trials conducted during seven high-tide events over the monitoring period showed that the sensor reading accuracy exceeded 90 per cent compared with manual measurements using a *staff gauge* installed for comparison. The early warning notifications received by the community provided, on average, an additional 45 to 90 minutes’ lead time before floodwater reached the floors of residents’ homes, depending on the rate of rise in water levels during each event. This timeframe provided the community with a significant opportunity to secure electronic goods, important documents and fish catches, as well as to move motor vehicles to higher ground.

Fig 2. Example of Coastal Area Building Construction
with a significant risk of storm surges

Nevertheless, technical challenges remain regarding the reliability of the power supply for the sensor devices, given that the electricity supply at some installation points is frequently disrupted during extreme weather, which coincides with the timing of the tidal flooding. During two incidents over the evaluation period, the sensors were temporarily unable to transmit data due to the backup batteries running out of power. Based on these findings, the implementation team recommends the addition of a small-scale solar panel with a capacity of 20 watt-peak, along with a larger-capacity *power bank*, as a backup power source in future developments. This will ensure the system can continue to operate autonomously (*off-grid*) without relying on the PLN electricity grid, which is prone to disruption during emergencies.

In addition to electrical issues, another challenge identified was the limited digital literacy of some residents—particularly the elderly—in using notification apps on smartphones. To address this, the implementation team equipped the system with manual sirens and physical indicator lights that can be observed directly without the need for digital devices, ensuring that early warning information remains accessible to all sections of society without exception. This dual-channel approach to information (digital and non-digital) has proven effective in inclusively expanding the reach of the early warning system's beneficiaries.

4.3 Dynamics of Community Empowerment and Participation

From the perspective of community empowerment, the formation of a coastal disaster preparedness group comprising 15 local residents—including representatives of fishermen, housewives and youth from the Karang Taruna organisation—represents a significant achievement in ensuring the programme's sustainability following the conclusion of the community service activities. This group has been equipped with basic skills in maintaining sensor equipment, response procedures when warning notifications are received, and an understanding of the operating principles of the amphibious foundation, enabling them to replicate its implementation independently in other households in the surrounding area. The formation of this group was carried out in a participatory manner through community consultations, ensuring that the selected members truly represent the trust of the local community, rather than being unilaterally appointed by the implementing team.

During the technical training process, a significant improvement in community understanding was recorded based on the results of simple pre- and post-tests administered to 40 training participants, with the average understanding score rising from 42 to 78 out of 100 following a series of awareness-raising sessions and technical training. This improvement indicates that a hands-on learning approach, in which the community is actively involved in the process of assembling floating drums and installing sensors, is far more effective than purely one-way outreach sessions.

This initiative also facilitated dialogue between the community and the sub-district administration, as well as relevant agencies—such as the Medan City Housing and Settlement Agency and the Regional Disaster Management Agency—regarding the need for policy support and funding to replicate the programme on a larger scale. These discussions resulted in a preliminary agreement that the outcomes of the community service activities would serve as input for the development of community-based tidal flooding mitigation programmes at sub-district level, whilst also opening up opportunities for replication in other coastal areas of North Sumatra's East Coast facing similar challenges, such as Deli Serdang Regency and Serdang Bedagai Regency.

4.4 Implementation Challenges and Strategies for Addressing Them

Several challenges were encountered during the implementation of the activities, which should be noted for the development of similar programmes in the future. Firstly, the limited timeframe for implementation—which coincided with the high-tide season—meant that the schedules for some field activities had to be dynamically adjusted in line with weather conditions and tidal patterns, thus requiring a high degree of planning flexibility from the implementation team. Secondly, budgetary constraints meant that the new amphibious construction prototype could only be applied to a single pilot unit, so its benefits have not yet been felt equally by all residents affected by tidal flooding in the area.

Thirdly, there were challenges regarding coordination amongst stakeholders, given that managing tidal flooding in port areas such as Belawan involves cross-sectoral responsibilities, including port authorities, the city council and the provincial government; consequently, the implementation of long-term solutions requires stronger policy synergy beyond the scope of this community service project. To address these challenges, the implementation team adopted an advocacy strategy by drafting a brief policy brief, which was submitted to the village and sub-district authorities for consideration in the development of follow-up programmes, whilst also documenting the entire process of the activities as *'lessons* learnt' that can be replicated by other parties with more adequate resources.

4.5 Implications for Programme Sustainability and Replication

Overall, the results of this initiative reinforce the argument that a combination of adaptive architectural solutions—in the form of amphibious construction—and digital technological solutions—in the form of an IoT system—can complement one another in building the resilience of coastal communities against the threat of tidal flooding. Amphibious construction serves as a medium- to long-term structural solution, whilst the IoT system acts as a short-term informational solution; thus, the combination of the two forms a more comprehensive mitigation strategy than if only one approach were implemented. This combined approach is also consistent with the concept of *'layered* resilience', which is widely recommended in contemporary literature on coastal disaster risk management.

The programme's future sustainability depends heavily on three key factors: the local government's institutional commitment to allocating a budget for replication; the capacity of community cadres to maintain and operate the system independently; and the availability of alternative funding schemes, such as partnerships with the private sector through *corporate social responsibility* (*CSR*) programmes, given that the project is located in a port industrial area surrounded by many large companies. If these three factors can be met, the empowerment model developed through this initiative has great potential to be replicated more widely along the East Coast of North Sumatra, thereby making a tangible contribution to community-led climate change adaptation efforts at the local level.

As a concluding note to this discussion, it is important to emphasise that the success of this initiative is not measured solely by the technical functionality of the two technologies implemented, but also by the shift in the community's perspective towards the risk of tidal flooding itself. Prior to the initiative, the majority of residents tended to view tidal flooding as a routine disaster that had to be accepted passively, without any structured adaptation efforts. Through a series of awareness-raising sessions, training and mentoring, a paradigm shift has taken place towards a more proactive attitude, whereby the community has begun to see itself as an active participant in mitigation efforts, rather than merely as victims waiting for assistance. It is this paradigm shift that will ultimately become the most important social capital for the sustainability of the Belawan coastal community empowerment programme in the future.

V. CONCLUSION

The community service activities in Belawan Sub-district, Medan City, demonstrate that the implementation of amphibious foundations and an Internet of Things (IoT)-based mitigation system constitutes a technically viable and socially acceptable approach as an adaptive solution for coastal communities in the face of tidal flooding threats. The prototype amphibious foundation was successfully demonstrated to function in response to water level fluctuations, whilst the IoT sensor system proved capable of providing real-time early warnings to the community. The success of this initiative was further supported by a participatory approach that actively involved the community from the planning stage through to the programme's sustainability, as evidenced by the formation of an independent coastal disaster preparedness group. For further development, it is recommended that the programme be replicated on a larger settlement scale, that renewable energy sources for IoT devices be strengthened, and that policy advocacy be directed towards local government so that this approach can be integrated into the City of Medan's coastal disaster mitigation strategy on a sustainable basis.

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