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Climate-adaptive vertical settlement for flood-prone areas in Central Java, Indonesia

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Abstract. Coastal flooding in Sriwulan Village, Sayung District, Demak Regency, has intensified due to climate change effects such as sea-level rise, land subsidence, and increased extreme weather events, causing daily inundation up to one meter, disruption of livelihoods, housing damage, and environmental degradation. This study proposes a vertical village design aimed at flood mitigation, optimal land use, enhanced resilience, and maintained social connectivity, supported by essential community amenities like green open spaces, children's play areas, and universal accessibility. The research follows a force-based design method, incorporating site criteria, resident needs, and local cultural values while applying sustainable architectural strategies that emphasize the holistic interaction of design factors. Community participation ensures alignment with daily life and priorities of Sriwulan residents. The objective is to improve living quality in flood-prone coastal areas and enable long-term climate adaptation, fostering a safer, more resilient, and sustainable future for the coastal community.

1 Introduction

Coastal flooding occurs when high tide inundates land or coastal areas below average sea level [1]. This inundation can last several days to a week, varying in height depending on the force of gravity. Water flows to the lowest point and fills the entire area [2]. Coastal flooding is a natural event caused by rising sea levels. It is explained that coastal flooding is caused by global warming, which is attributed to melting ice in the polar regions, land subsidence, high sea waves resulting from the gravitational forces of the sun and moon, increased abrasion intensity, and drainage damage [1,3]. The IPCC (Intergovernmental Panel on Climate Change) report, which states that by the end of the 21st century, there will be a global sea-level rise of 0.52-0.98 m, provides evidence for coastal flooding driven by global warming and melting ice in the polar regions [4].

In addition to global warming, land subsidence is a cause of coastal flooding. Land subsidence can occur due to loading. It is explained that if the supported rock mass has a higher density than the support, then the area will experience land subsidence [5]. Additionally, land subsidence, a cause of coastal flooding, can result from excessive groundwater extraction. An example is land subsidence in the North Semarang area, Indonesia. The continuous land subsidence in the region has lowered the topographic height

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in the North Semarang area [6]. Additionally, the North Semarang area is bordered by the Java Sea, which frequently causes coastal flooding.

Since the 1980s, Demak Regency has been among the areas most frequently affected by coastal flooding, leading to changes in land use. There are 17 villages in three sub-districts of Demak Regency — Sayung, Bonang, and Karangtengah — that are affected by coastal flooding. Of the three sub-districts, Sayung District is the most severely affected, with 10 of its 17 villages experiencing impacts. The affected villages include Sriwulan, Bedono, Purwosari, Gemulak, Sidogemah, Tugu, Timbulsloko, Sidorejo, Surodadi, and Banjarsari [6,7]. Based on Google Earth data, almost all villages in the Sayung District experienced flooding from the Semarang-Demak border to the northernmost tip of the District, spanning approximately 11 km. The average height of coastal flooding in the Demak area ranges from 50 to 100 centimetres.

Several districts in Demak Regency experienced land subsidence. In the coastal area of the Demak Regency, the land subsidence rate ranges from 0.06 to 1.15 meters per year. The least subsidence usually occurs in areas near the coast, while the highest subsidence generally occurs in areas with high industrial density. Based on DEM predictions for 2025, the lowest elevation on the coast of Demak Regency is estimated to reach -35 metres. Seawater inundation, also known as rob, occurs in several locations in Demak Regency, especially along the north coast of Sayung District [6,8,9].

Sriwulan Village, located in Sayung District, which has a coastline of 81,000 kilometres, is very vulnerable to various types of natural disasters, including coastal floods caused by the ebb and flow of seawater. Based on Demak Regency Regional Regulation Number 1 of 2020, which amends Regional Regulation Number 6 of 2011 concerning the 2011-2031 Regional Spatial Planning Plan, the spatial structure policy designates Sayung District as a PKK that serves activities at the sub-district or village level [10]. Sayung District plays a vital role in the agricultural and industrial sectors, as evidenced by its extensive agrarian land, numerous ponds, and factories.

Therefore, the problem formulations are: What is the optimal design solution that enables the designed settlement to respond to coastal flooding, and how can a vertical village be created within the local community's socio-cultural context to build an alternative town that is responsive to flooding? The primary objective of the design is to establish an arrangement of village buildings in Demak Regency, Sriwulan Village, that serves as an alternative in the event of flooding, without altering the community's interaction patterns or the natural environment. The second is to plan and design the arrangement of flood-prone areas in Demak Regency to improve the environment's functions and quality, using an alternative vertical village concept [11].

The discourse on developing the economy and environment of coastal regions is crucial and has become increasingly challenging. Nonetheless, there remains a deficiency in studies regarding the integration of This study will concentrate on this specific event and aim to elucidate its fundamental characteristics by initially analysing the region's physical landscape [12]. The conventional approach to coastline management, utilising seawalls, has become unsustainable due to persistent land subsidence and continually rising sea levels. The current literature primarily emphasises extensive coastal defence, land reclamation, or traditional dwelling restoration. Nevertheless, scant attention has been given to community-oriented, culturally embedded vertical settlements that harmonise the effects of climate change with indigenous subsistence practices. The originality of this article is based on its force-based-design methodology and developed with a focus on matching physical-environment components (flood height, land subsidence, sea-level rise) and sociocultural components (interaction patterns, community’s priority, and spatial tradition) [4,8]. Thus, the aim of this paper is to design an optimal and culturally sensitive vertical village that will increase flood resilience, strengthen climate stewardship, maintain community links, and provide improved sustainable living conditions for those who live in the Sriwulan Village.

This study addresses a critical gap in the literature by developing the concept of a sustainable architectural design termed "Kampung Vertikal," tailored to the social and cultural characteristics of coastal communities, which optimizes limited land use through multi-story housing while enhancing resilience against coastal flooding via retaining walls, land elevation, elevated structures, and infiltration wells [13]. Its novelty lies in the holistic integration of flood mitigation techniques, land efficiency, and strengthened social connectivity along with cultural preservation through public facilities and eco-friendly green spaces; the objective is to propose an adaptive, sustainable settlement model for flood-prone coastal areas that maintains environmental quality and local values in Sriwulan Village, Demak.

2 Research methods

The design is produced by applying the locality design method, with an approach to residents' daily activities. The data collected includes existing conditions, activities, and phenomena that are taking place at present, which will later be used to analyse and identify problems in the form of the inability of poor people to meet their housing needs, as well as the decision to design a vertical village as a project proposal for the development of a sustainable vertical town aimed at overcoming coastal flooding and slums, optimising land, and being more cost-effective than relocation [14]. The vertical village maintains the local character, fostering a sense of togetherness that helps overcome problems. The design idea is then integrated with other examples of built vertical villages, implemented, and developed, considering the limitations of the specified location [15].

3 Results and discussions

3.1 Site Selection

The selection of a suitable location/site for the project is based on the required site criteria. The selected site is in one of the villages most severely affected by coastal flooding (Rob Flood). Sriwulan Village, located in Sayung District, Demak Regency, is one of the villages affected by floods, as shown in Figure 1. Sriwulan Village experiences significant coastal flooding that inundates hundreds of hectares of residential areas, including houses, schools, public facilities, ponds, and offices, and damages other public infrastructure.

Fig. 1. The Sriwulan Village Location

The second criterion for site selection is that the selected site functions as a residential area and is strategically located near workplaces and service centres. Thus, the land designated for residential use is marked in red, as bounded in Figure 1. This project aims to design a housing area resilient to coastal flooding. The travel time from the site to workplaces and service centres is approximately 30 minutes. The selected site has good access to public facilities, adequate infrastructure, and amenities.

3.2 Site Data

The selected site is located on Jalan Sunan Kalijagat Selatan, the main road in the Citizens Association (RW) 7 area, with a total area of 15,000 m². This site was chosen because its land use aligns with the land use plan and is within 1 km of the existing village. According to the site regulations of Central Java Province and Semarang City Regional Regulation Number 2 of 2020, the building coverage ratio is 80%, the floor area ratio is 2.4, and the maximum building height is 15 meters [10].

3.3 Site Analysis Based on Activities Program

The analysis of activity programs aims to identify residents' activities in Kampung RW 7 within the planned building, so that an appropriate program can be developed to accommodate their activities. The identification of activities encompasses the program of activities scheduled for the planning project. The residential zone is located on floors 1 through 4, comprising two types of housing units and several social spaces on each floor. The supporting facilities zone is situated in the central part of the site, featuring business courtyards, kiosks/shops, an Early Childhood Education (PAUD), and a pharmacy on the first floor; a prayer room on the second floor; and gathering spaces on the third floor.

3.3.1. Housing

According to Karmilah, most residents of Desa Sriwulan originate from Semarang, giving the community an urban character [7]. The Pondok Raden Patah housing complex is located in RW 7 and is classified as a simple housing type (very simple house/RSS), as shown in Figure 2. The housing program accounts for 50% of the total building area and comprises two types of units. First, Type 45 m² housing with 51 units, each accommodating up to 5 persons. Second, Type 36 m² housing has 384 units, each accommodating four persons. The determination of these housing types is based on family-size data in RW 7 and on the standards for apartment-unit spaces.

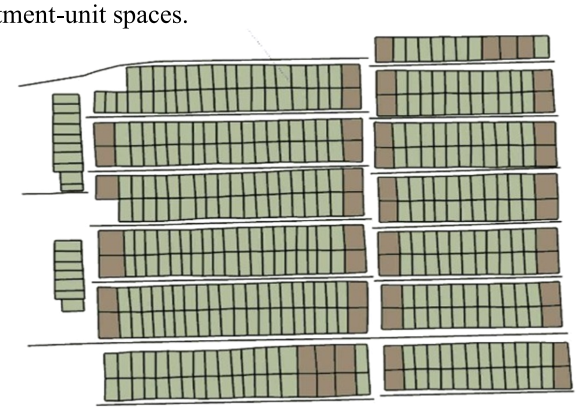

Fig. 2. The Existing Housing Location

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3.3.2. Kiosks

The business courtyard area is designed to accommodate residents who run small businesses as street vendors (PKL). These vendors originally sold their goods mostly in front of their own homes. The business courtyard is zoned in the centre of the site to facilitate easy access for residents to shop while maintaining the privacy of the residential areas.

3.3.3. Prayer Room

A prayer room is provided to meet residents' needs for worship, in accordance with Indonesian national standards for facility provision based on a residential area's population size.

3.3.4. Early Childhood Education Centre

The Early Childhood Education Centre/PAUD facility is provided to fulfil the educational needs of children aged 1-5 years. Therefore, its location must be nearby and safe for easy access. Additionally, the provision of this centre follows Indonesian national standards for facility requirements based on the area's population size.

3.3.5. Healthcare Facility

The pharmacy is a vital healthcare facility that supports residents' well-being. Its provision also complies with Indonesian national standards for facility allocation based on the residential area's population size.

3.3.6. Areas

Communal spaces are distributed throughout the residential units, creating cross ventilation within the building masses. The scattered layout of communal areas aims to create an informal, irregular atmosphere similar to that of traditional village settings.

3.4 Design Concept and Building Form

3.4.1. Zoning and Massing Concept

This concept considers two main components: site, land use and community. The site and land use component emphasises accessibility (residences close to communal spaces) and zoning (functional area division) [15]. The community component emphasises integrated public spaces, including gardens, shops, and gathering areas. The settlement pattern is linear, following the road's direction, as shown in the site conditions in Figure 3.

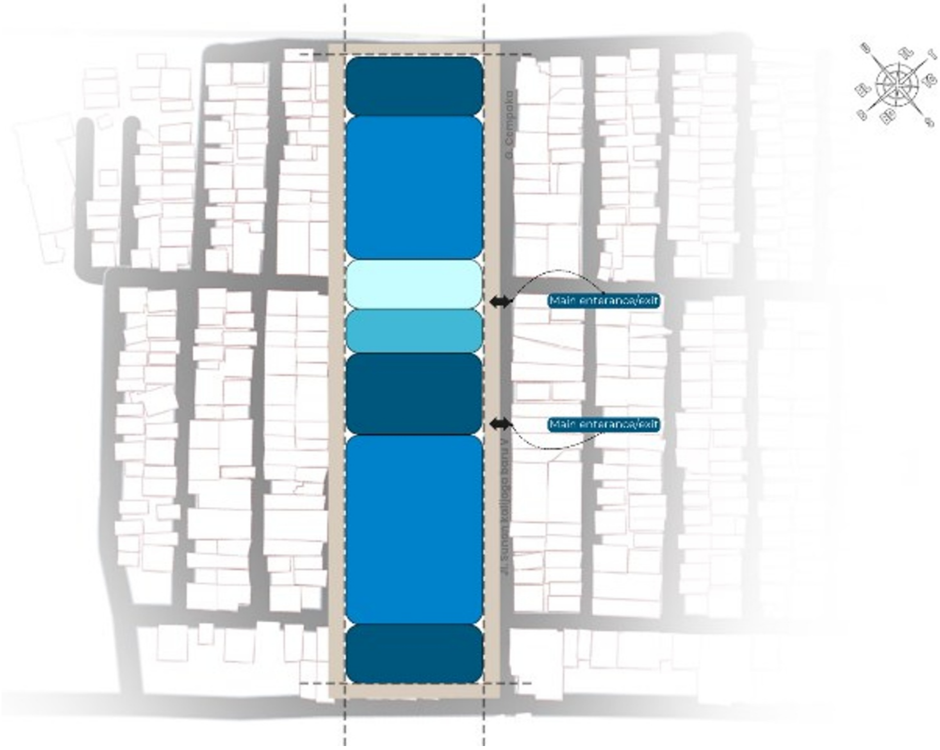

Fig. 3. The Zoning Concept

3.4.2. Building Form Concept

This concept considers two components: health, with design criteria that help maximise natural sunlight to reduce electricity consumption [14]. The building is composed of five distinct masses. The division of building masses is adjusted according to the zoning concept, which incorporates natural elements by orienting buildings along the sun’s path, as shown in Figure 4.

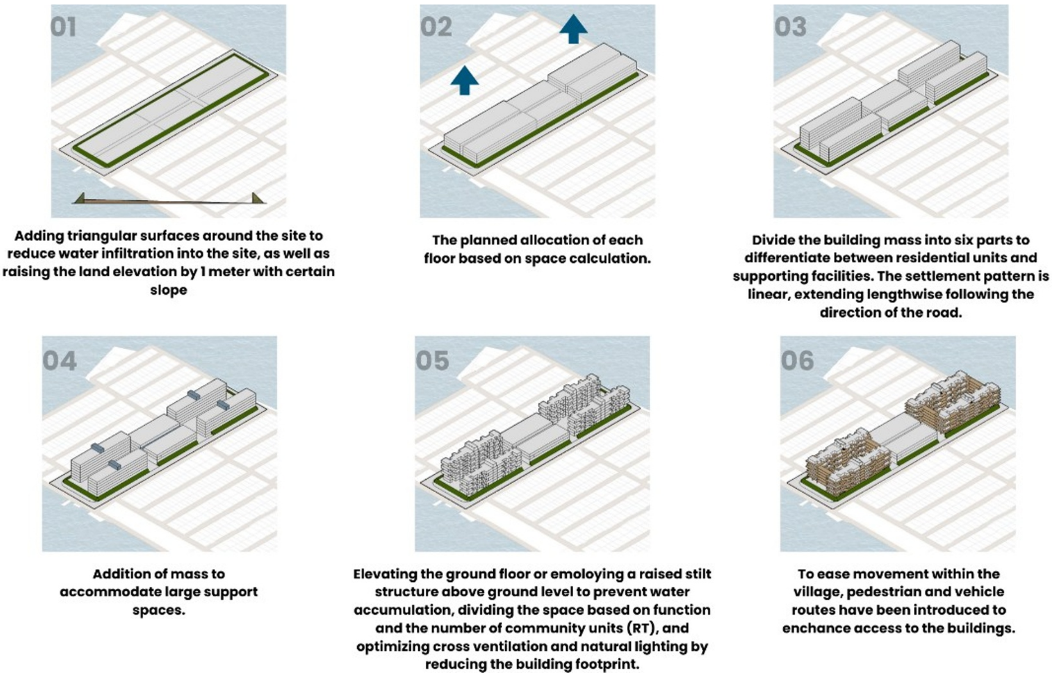

Fig. 4. The Building Form Concept

3.4.3. Flood Mitigation Concept

This building planning concept will implement several solutions to prevent coastal flooding. First, triangular-shaped embankments around the site will minimise water intrusion and raise the ground level by 1 meter, with a sloped surface, as shown in Figure 5a. The second solution is to increase the ground floor or to use a stilt structure above ground level to prevent flooding, as shown in Figure 5b. The following mitigation utilises infiltration wells around the site's perimeter and green open spaces within the building, as presented in Figure 6.

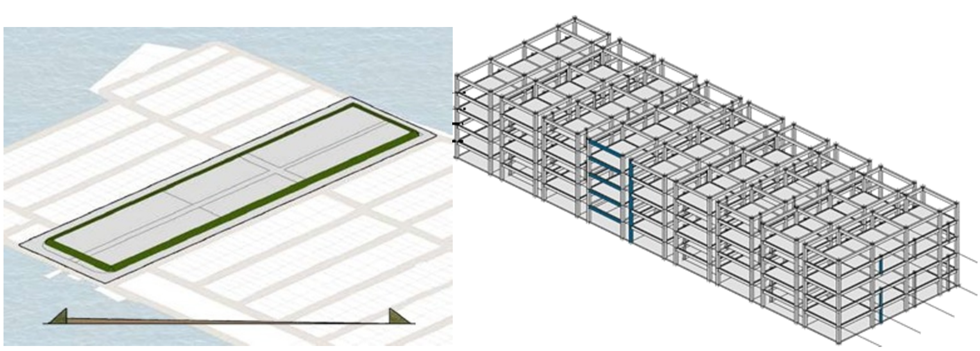

Fig. 5a. The Triangular-Shaped Embankments Concept; **5b.** The Raising Ground Floor

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Fig. 6. The Infiltration Wells Concept

3.4.4. Building Design

Therefore, the vertical village design, presented in Figure 7, for Sriwulan Village, Demak, Central Java, is a novel solution to recurring coastal flooding. This design aims to maximise land use, improve flood resilience, preserve social contact, and provide sustainable housing.

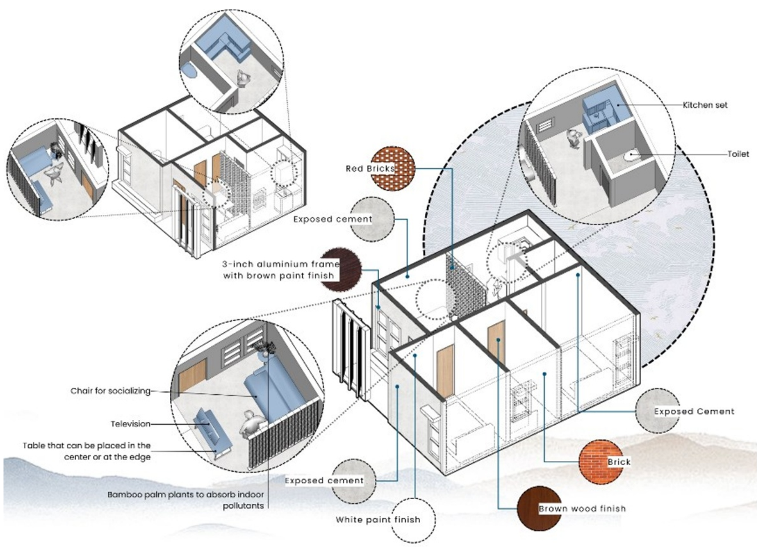

Fig. 7. The Building Materials Concept

3.4.5. Climate Adapting Design

The concept to be applied to adapt to climate change is green roofs, which can absorb rainwater, reduce runoff, and provide green space that increases the comfort and sustainability of buildings [14]. Reflective roofing materials are chosen to minimise heat absorption, reducing the need for cooling inside the building, as shown in Figure 8. Furthermore, solar energy is a renewable resource because it is abundant and continuously provides energy to Earth. Residents can use solar energy for various purposes. For example, outdoor lights in vertical villages use solar panel lights, designed as independent lighting systems that utilise solar energy via panels installed on each lamp.

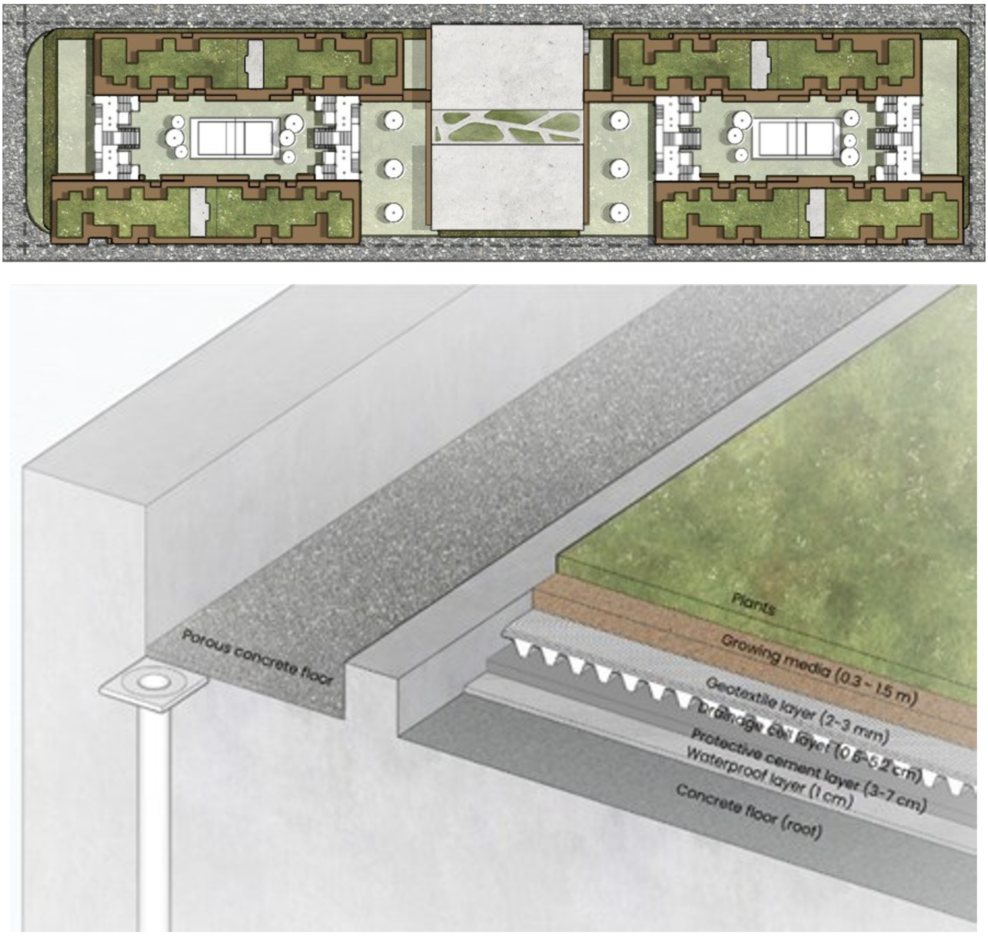

Fig. 8. The Green Roof Top Concept

4 Conclusion

The design of the vertical village, responsive to coastal flooding in Sriwulan Village, Demak, offers an innovative solution to recurrent coastal flooding, aiming to maximise land use, enhance flood resilience, maintain social interaction, and provide sustainable housing. Based on sustainable architecture principles, this design employs Plowright's force-based approach, integrating external and internal forces to align with the local community's socio-cultural context. The design strategies include zoning, mass arrangement, adequate circulation, and the use of water-resistant and recycled materials on the façade. The housing's spatial layout is designed to meet community needs. At the same time, the building structure is designed to withstand coastal flooding using cement foundations, a modular system, and roofing that ensures proper rainwater drainage. This vertical village is expected to serve as a model for similar settlement developments in flood-prone areas.

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