SPACE AND PANIC. The application of Space Syntax to understand the relationship between mortality rates and spatial configuration in Banda Aceh during the tsunami 2004

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Abstract

The aim of this paper is to reveal the correlation between mortality rates from the tsunami of 2004 and the spatial structure of Banda Aceh’s street net. Structurally, the city is divided up in several small villages, which consists of a couple of urban blocks. The mortality rates for each of these local villages, gained from Japan International Cooperation Agency (JICA), were correlated with space syntax analyses of Banda Aceh’s street network.

As it turns out, a high number of segregated streets reduce the degree of peoples’ orientability in case of panic. However, observations of a tsunami wave’s behaviour show that a spatially broken up street can also reduce the water speed when it hits a city. Conversely, an orthogonal network styled street grid can generate high water speed through streets, but has on the other hand a high degree of orientability for its inhabitants for escaping the tsunami in case of panic. As it turns out from the interviews of tsunami survivals, people fled to the opposite direction of the tsunami and they followed the crowd. The survivors expressed that in the panic flight situation the visual orientation matters and rational thinking in way-finding reduces.

Therefore the challenge in re-building cities in tsunami prone areas is to both make an orientable street network with a spatial structure that reduces a tsunami’s water speed.
1. INTRODUCTION

The Tsunami heavily affected Banda Aceh 26th December 2004. Around 71,475 People are reported dead and missing while around 65,500 inhabitants are displaced as the tsunami also destroyed around 12,972 of houses in the city. It is half of the total number of houses in Banda Aceh (JICA, 2005). Structurally, the city is divided up in several small villages, which consists of a couple of urban blocks. Each village has a local community house and a local administration board. In this way, it was possible to have a detailed overview over how the tsunami affected the local inhabitants and their properties. From the report of the survey team from Japan International Cooperation Agency (JICA) in 2005, it was possible to get the mortality rates from the 2004 tsunami for each of these local villages. These numbers were correlated with space syntax analyses of Banda Aceh’s street network.

When revealing the literature on the relationship between urban form and panic, knowledge is lacking. Due to ethical reasons, it is more or less impossible to carry out experiments with human beings with purpose to gain knowledge on how they orient through various types of built environments in panic situations. There exist some studies with experiments on how a group of mice react in a room when it gets filled with water and how the mice behave at the escape exists. Conversely, when revealing the literature on the relationship between urban form and its effect the water flow speed, there exist some research results from model studies.

Therefore the study of Banda Aceh can contribute with some knowledge on the relationship between urban form and human behaviour in case of panic. The first part of the paper will reveal the literature in the field of tsunami disasters, safety policies, and human behaviour in panic situations. The second part reveals the results from the Banda Aceh case, while part three discusses future planning and building challenges for built environment with tsunami threats.

2. THE DEFINITION OF TSUNAMI

Tsunami is Japanese word. The direct translation means harbour wave. “...As the word is originally from Japan, tsunami phenomenon is very common in this country, it can happen approximately once in every ten years. The word “tsunami” became internationally popular after the Meiji-Sanriku Tsunami in 1896 and the Showa-Sanriku Tsunami in 1933 as news reports of devastating damages appeared around the world” (Takahashi, 2005).

United States Federal Emergency Management Agency (FEMA, 2009) explained the tsunami phenomenon as “...it occurs when there is rapid, large-scale disturbance in a body of water. The most common triggering events are earthquakes below or near the ocean floor, but tsunami can also be created by volcanic activity or landslide.” A tsunami can be triggered by a local source or also from a source far away across the ocean. U.S. Geological Survey (USGS, 2005) reported that an earthquake in 1960 in Chile produced local a tsunami as well as triggered massive waves that travelled more than 800km/h across Pacific Ocean and reached the Japanese coast within 22 hours.

The tsunami from 2004 is considered as one of the biggest earthquake and tsunami that hit coastal communities in human history. On 26th December 2004 an earthquake in the Indian Ocean with the epicentre nearby the west coast of the Indonesian island Sumatra created large tsunami waves. These extremely large waves heavily hit the coastal areas of the western islands of Indonesia, western Thailand and
Malaysia, Sri Lanka, Burma, Bangladesh, the eastern coast of India, Madagascar, Maldives, Somalia, Kenya, Seychelles, Tanzania and South Africa. The earthquake had a magnitude between 9.1 and 9.3 and the tsunami waves killed 227,898 people in fourteen countries. Indonesia was hardest hit. In some of the coastal areas waves up to 30 metres high were registered.

3. TWO DIVERGENT VIEWS ON TSUNAMI SAFE BUILT ENVIRONMENTS

There are two divergent views on how to reduce the effects of a tsunami in built environments. One view, the technical one states that a built environment with a broken up street network will reduce the speed of water flow of a tsunami wave. The engineers dealing with calculating the speed, size and forces of tsunami waves hold this standpoint. According to this view, it gives people extra time to escape from a tsunami. Figure 1 shows the spatial principles of a tsunami safe city according to the technical view.

![Figure 1](image.png)

*Figure 1:* A model showing the spatial principles for tsunami-safe cities based on the technical view; Visually broken up streets with many turns are effective to reduce the force of a tsunami wave but it can be deadly for escaping people in panic situations.

The other view, the psychological one, states that the visual orientation plays a role when people are in panic. Most people cannot think rationally in panic situations and they tend to flee in the opposite direction of a danger. The perception psychologists hold this view. It implies that a built environment with an easy orientable spatial structure will reduce the mortality rates in the case of panic. Figure 2 shows the spatial principles of a tsunami safe city according to the perception psychology view. Therefore the next section will discuss the results from these two divergent view’s empirical data.
3.1 The tsunami wave’s behaviour – the technical view

Many scholars around the world are investigating the characteristic of a tsunami wave. Japan, US and countries in the Pacific region take tsunami as a serious threat. Up till now, nearly 60% of the tsunami incidents have occurred in these countries (IOC, 2008). Therefore, intensive study about it characteristics and behaviour is substantial.

The tsunami waves are extreme long waves. Therefore it is possible to determinate the free water surface to calculate tsunami overtopping and impulsive wave forces according to the Reynold-averaged Navier-Stoker equatations (Tomita, Honda and Kakinuma, 2006, p. 2). These equatations have three dimensions, which make it possible to calculate the amounts of m3 of the water volume from a tsunami wave.

An integrated numerical model called STOC (Storm surge and Tsunami simulator in Oceans and Coastal areas) has been developed to produce simulation of a tsunami wave’s behaviour on urban form. Using the STOC simulation, researchers are able to study how the tsunami wave surge the coastal area and react toward different structures or environment characteristic such as shallow water, river, canal, etc (Tomita, Honda and Kakinuma, 2006).

Another model, The MARS-method, simulates the temporal dimensions on how a tsunami wave affects the different areas in a city. It shows how and when (in terms of minutes) the water flow hits various public spaces in a city (Hiraishi and Yasuda 2009). The MARS-method takes only into account that the buildings are not swept away by a tsunami. The purpose is to make an establishment of escape routes. The analyses are based on Masan city in Korea, a city with high density of the built mass and several underground spaces.

Amateur videos and field evidence from the 2004 tsunami produced useful information on the characteristic of the wave’s behaviour against a city’s spatial structure. The same account for the Japan tsunami in 2011 (Youtube, 2011). As tsunami is a long length wave, it is difficult to stop a tsunami when it penetrates a coastal city. Dependent on a city’s spatial structure, a tsunami wave can slowly generate and produce more

Figure 2: A model showing the spatial principles for tsunami-safe cities based on the psychological view; Straight streets that are perpendicular to the wave’s direction are easily orientable for escaping people, but it increases the speed and forces of a tsunami wave when it hits a city.
devastating waves within the city (Tomita, Honda and Kakinuma, 2006). A youtube video on the tsunami footage in downtown Banda Aceh (Youtube, 2007) shows that the speed of the wave was slowly increasing, as it had no obstacles along its way. The back wave pushed the front wave, while at the same time small secondary streets feed water into the big wave at the main streets.

A tsunami wave has a similar behaviour pattern as wind. Studies of Storm Surge and Tsunami Simulator in Oceans and Coastal Areas (STOC) show that a tsunami wave has a high speed in open and straight line channels, especially when these line channels have same direction with the water force. This argument is strengthened by an amateur video recorded in Banda Aceh during the 2004 tsunami. The video shows that the streets having the same direction as the water flow suffered bigger damages and the water flow was faster in those streets that are perpendicular to the coastline.

As it turns out from the technical model studies, a built environment with long and straight streets located 90 degrees on the coastal line seems to be very vulnerable for a city when a tsunami wave hits it. This street form increases the speed of the water flows (Tomita, Honda and Kakinuma, 2006, p. 7) and the effects are that more inland areas are affected by a tsunami than a broken up street grid. Additionally, rubble and debris swept by tsunami make the wave even deadlier in these straight long streets. Therefore these kinds of streets create channel like areas with a high concentration of water. In additional, connected side streets create and immense water forces that can sweep almost entire object along a tsunami’s path.

However, Tomita, Honda and Kakinuma, based their observation on the result of tsunami in Banda Aceh. As they claim, some structure such as breakwaters, coastal mounds, rigid houses etc, were effective in reduction of tsunami momentum behind them (Tomita, Honda and Kakinuma, 2006, p. 1). This indicate that a tsunami force can somehow be reduced or even diminished by using some of these structures. All researchers with a technical approach propose a warning system in terms of a sign system, escape towers, and marked escape routes up to the hills. The challenge for urban planners is how to give a city a form for reducing the effects of a tsunami. Where to locate the various escape routes and escape towers in the urban fabric with purpose for way finding in the case of panic is a challenge for rebuilding cities after a tsunami.

3.2 The human behaviour in case of panic – the psychological view

Panic can be associated to several circumstances, such as financial panic, mental health panic, etc. In this article, the term panic is used from a sociologicist point of view. In his book Collective Behaviour, the sociologist LaPierre expressed panic as dysfunctional escape behaviour generated by fortuitous, ever varying circumstances, but involving impending danger (LaPierre 1938).

During a disaster strike, people will find them self in an uncomfortable and life threatening situation. At this point, people will escape from this situation by running to a safe place. This flight behaviour can vary from person to person depending on several aspects such as mental health, condition of the environment, knowledge of the surroundings, and knowledge about the disaster it self (Chu, Li and Zhao, 2005). However, in some circumstances, panic can be seen as a collective behaviour. As Quarantelli explains in his article The Sociology of Panic that panic has always been considered part of the subject matter of the sociological specialization of collective behaviour, which deals with non-traditional and newly emergent forms of social action (Quarantelli, 2001).
Carrying out experiments for finding out how human beings reacts and orientate in the case of panic in built environments is not possible for ethical reasons. Some experiments with real escape panic were tested out in mice escaping from a water pool to a dry platform through one exit door. The exit door varied in width and numbers. When a mouse was used twice in an experiment, it could find its way to a dry place faster during the second experiment. As the research results indicate, panic behaviour depends on the number of people in a room, the size of the room and the effect of allelomimesis among people (Saloma et al, 2003). These results are useful for planning escape routes out of rooms, but difficult to apply in the planning and design of built environments.

Various agent simulation models are also use for studying the pattern of escape panic. In their research Chu, Li and Zhao developed an agent-based model where a difference between individuals in large crowd was used. An asymmetric distribution of information is applied, where some of the agents hold more information than others (super agents). As the model studies show, the use of these super agents made the escape flow and time much more effectively, since the other agents simply follows the behaviour of their randomly closed neighbours (Chu, Li and Zhao, 2005). Similar results were also found in the research of Puckett, where the role of trained leaders and ‘natural born’ leaders influence the escape time for crowds (Puckett 2009, p. 4). As he indicates, agents without any path knowledge became stuck at a simple wall. If there were an attractive place behind the wall, the agents merely kept bumping against it (Puckett 2009, p. 22). This information suggests that people tend to follow the crowd and that visual orientation matters in case of panic.

Short after the 2004 tsunami, a group of researchers from Japan made a survey in Banda Aceh and its surrounding areas. The purpose was to make a questioner survey of people affected by the tsunami for collecting information on what happened, and what were expected by the affected people to be safe against future tsunamis. The survey focused on theses survivors’ location, how they managed to survive, and the size of the wave. As it turns out, knowledge on tsunami as an effect of earthquakes was rather poor. 43% of the people run away before the tsunami came and 51% run away after seeing the tsunami. Most of the people managed to survive by climbing up a roof or up a tree, hold on floating objects, or through swimming (Iemura et al, 2006).

There exist no research on the relationship between urban form and human behaviour in panic situations. However, it is essential for the urban planner to know how people react during a panic situation in a tsunami strike when rebuilding or planning cities with a tsunami risk. Knowledge on what kind of urban spatial features for easy escaping is needed for reducing the mortality rates of a tsunami. The only way for testing this view is to get empirical data on neighbourhood level, correlate the results with the space syntax analyses and to interview survivors from the 2004 tsunami.

The tsunami in Banda Aceh happened in the morning, at a time when most people were at home. Therefore research on Banda Aceh can provide knowledge on human behaviour in built environments in case of panic, in particular that most of the missing and killed people were reported on basis on their home address.

4. THE BANDA ACEH CASE

Banda Aceh city is the provincial capital city of the province Aceh, located on the island of Sumattra. Before the tsunami, about 263,669 people were living there. It is located on the North-Western tip of Indonesia, the closest major city to the epicentre of the 2004 earthquake. The epicentre was about 255 km southeast from...
Banda Aceh. While the wave reached more than 4 km into the inland, the tsunami produced massive devastation in the city of Banda Aceh.

Tsunami is a rare event in Banda Aceh. In fact the city has no record on tsunami earlier. This makes people unaware about the sleeping danger that lies next to their homes. Although the 9.2 magnitude earthquake prior to tsunami 2004 has produced several indications toward the arrival of tsunami wave, few inhabitants in the city was aware that the 2004 tsunami was on it way towards the city. Figure 3 shows how far the tsunami hit Banda Aceh. Lack of knowledge about the disaster make the city very vulnerable when it takes place. In addition, Banda Aceh was also struggling with a long civil war, which even more makes it difficult to implement various escape strategies.

![Figure 3: Map of Banda Aceh with the tsunami borders and boarders of the local villages.](image)

Like many other cities in Indonesia, Banda Aceh lies close to the fault line of an active tectonic plate that is constantly moving. Moreover, this city is also located on the border of following three continental plates; the Euroasian plate, the Indian plate, and the Australian plate. Therefore the city has large earthquakes and tsunami risks, in which should be taken into account for planning tsunami preventive actions such as warning systems and building a tsunami proof built environment.
4.1 Relationship spatial structure and mortality rates

The city vulnerability toward 2004 tsunami is reflected by high number of dead within the city it self. Banda Aceh alone had around 30% of the total number of killed people in the 2004 tsunami. The number of death is not fairly distributed within the affected area in the city. It depends on the location of casualties, density, condition of the environment, distribution of wave force, etc.

The basis for the space syntax method in urban studies is the axial map. The street and road network in built environments is represented with the longest and fewest sight lines. Therefore, direction changes in terms of visibility are presented. The notion of syntactic step on an axial map is meant to represent a change of direction from one axial sight line to another. Since visual orientation matters in panic situations, a space syntax analysis indicates the degree of visibility in various streets in a whole city.

As research has shown, streets with the fewest direction changes to all other streets in a built environment tend to be the most vital shopping streets with the highest flow of human movement (Hillier et al 1998). Conversely, streets with a high number of direction changes tend to be silent streets (Hillier 2005). In extreme spatially segregated neighbourhoods visitors tend to get lost (van Nes, 2007).

Banda Aceh consists of a large group of small villages. Most of them are of a size of an urban block, consisting of 20-40 streets that are from 2.5 to 4 meters wide. Each of them has a local community with detailed overview over its local inhabitants. Therefore, it was easy to get an overview over the number of death from the local Red Cross for each village (or local neighbourhood).

The mortality numbers of each neighbourhood were plotted on a map (figure 4). The mortality rates are visualised as circles. The larger the circle, the larger mortality rate for each neighbourhood or village. As can be seen on the map, a high number of killed or missing people were found in the local villages or neighbourhoods nearby the coast. Moreover, the Banda Aceh casualty map indicates that certain areas at the tsunami’s border have high mortality rates. Survivors in these particular areas expressed their difficulties in escaping the tsunami. One of the obstacles explained was the difficulty to find their way out of the neighbourhood due to a labyrinthy type of street network.

As the city is formulated by combination of several villages that create urban blocks, most of the street in this area was developed from the previous villages’ pathways, which follows the land border pattern. This generates a labyrinthy street where an eye orientation level is low.
Figure 4: Map of the mortality rates in each village in Banda Aceh.

Figure 5 shows a global integration of the street and road network of Banda Aceh as it was in 2004 before the tsunami. As can be seen on the map, the colonial old city centre has a highly spatially integrated network structured street and road net. Outside the city centre, there exist several neighbourhoods with a segregated broken up street network with several cul-de-sac streets.
When comparing the mortality rates with the spatial analyses (figure 6), some striking results can be seen. The more spatially segregated the street network is in a local area, the higher mortality rates. These areas consist of a labyrinthy broken up street network and with several dead end streets. A high spatial integration of the street network contributed to lower mortality rates. These areas consist of a highly inter-connected street network with many escape routes. In the case of Banda Aceh it is the historic city centre. All these selected area (villages) has similar density rates.

At the tsunami’s border line, some neighbourhoods have very high mortality rates. They are coloured in grey circles in figure 4. Seemingly, many people did not make it to escape to the highly globally integrated north-south main route through the whole city. Probably many of them got trapped in dead end streets or got lost in the labyrinthy street net.
Figure 6: Map showing all mortality rates in Banda Aceh combined with space syntax
Figure 7 shows a zoom in of the area with the villages with high and low mortality rates. Area 1 is part of the old city centre. In those villages with a high integration of the street net, named Area 1, consist of the village Peunayong and Mulia. These villages have a total area of 903,117 m². The mortality rates were around 819 people, which means that at least one person died in every 1,103 m². These villages are marked as small grey circles in figure 7. In those villages with a low integration on the street net, named Area 2, consist of the villages Punge Blang Cut, Punge Jurong, Lampaseh Kota, Merduati, and Keudah. These villages have a total area of 2,005,306 m². The mortality rates were around 10,673 people, which mean that there is at least one person died in every 188 m². All of these villages have similar density on the built mass and are located on the border of the tsunami heavily damaged area. These villages are marked as large grey circles in figure 7.

The global integration analysis shows the degree of visibility in terms of the total number of direction changes from every street to all other (topological distance). It measures a city’s “to-movement” potentials. In case of panic, the main route network seems to play a role in escaping out of a neighbourhood. Moreover, adding metrical distances or radii must indicate the locations for the shortest as well as the most orientable escape routes. Therefore angular analyses with various metrical radii provide insights on a city’s “through-movement” potentials.
According to Hillier and Iida, a city consist of a very few number of long streets, ending up at another long street with an angle close to 180 degrees, and a very high number of short streets, ending up with an angle close to 90 degree to another street (Hillier and Iida, 2005). This visibility property of a city’s street and road network makes it possible for people to orient from the edges towards the city centre with a few numbers of direction changes and small angular deviations. In particular in large complex cities, the angular analyses can show how the city’s edges can reach the centre through the network of the main routes. The long lines have thus long visibility properties, and at the junctions one can see how the long lines continues with a small angular deviation to another long line. The axial line is still the basis for the angular analyses. When processing the angular analyses in Depthmap, the software breaks up the axial lines at every junction. At every junction an angular weighting is done. The fewer direction change in terms of angular deviation, the higher values on the street segments.

One of the critics of the space syntax method was a lack of the metrical properties in their analyses (Ratti 2004). Now it is incorporated in the calculations. As research results show, the geometrical and topological distances correspond with the pedestrian and vehicle flow rates and the location pattern of shops more than the metrical distances. However, when applying metrical radii in the angular and axial analyses, some striking results can be seen. The degree of vitality of the various local areas can be seen in the analyses with a low metrical radius, while the main route network is highlighted in the analyses with a high metrical radius. Streets with high integration values with a high metrical radius tend to be the potential routes for through movement. Conversely, streets with high integration values with a low metrical radius tend to be potential meeting places for the neighbourhood. When comparing these two analyses with one another, the most vital urban areas tend to be where streets have high integration values with both high and low metrical radii (van Nes, Berghauser-Pont, Maschoodi, 2011).

Figure 8 shows local angular choice analyses with a low and a high metrical radius of the same area from figure 7 in Banda Aceh. The circles with the location of the 5 villages are shown on both maps. When revealing the three worst affected villages, there are poor connections from the local street network to the main routes. The integrated streets with a low metrical radius tend to be on different streets than those with a high metrical radius. Moreover, there are few east-west connections from these villages. The two least affected villages have main routes through the local areas (high metrical radius), good east-west connections, and the main routes are on the same streets with high integration with a low metrical radius.
In order to find out how the survivors experienced their escape from the tsunami inside the three worst affected villages, in-depth interviews were carried out. The purpose is to find out how people experienced the built environment in a panic situation – in particular when knowledge on tsunami is low. This information is lacking in the survey of the Iemura, Takahashi and Pradono.

4.3 The survivors’ behaviour story in the segregated villages

It is still difficult to know how exactly the various escape patterns was in Banda Aceh, as many people did not make it to the next day to tell their story. However, stories from the survivor produced some indications on how people actually react during their panic flight and how urban features give its contribution in escaping the wave.

According to figure 4 with the distribution of death in all villages in Banda Aceh, some areas located on the edge of the inundation area have high mortality rates in comparison to other areas with similar inundation level and density. Therefore, in depth interviews were made of survivors in the most segregated villages about their escape behaviour during the tsunami. The approach was a qualitative approach, where no standard questionnaires were formulated. The aim was to let the tsunami victims tell their stories during the escape and how they experienced the surroundings.

The interviews were done informally. No set of questions was distributed to the interviewees because the various communities have been approached by several NGOs in the past after the 2004 tsunami. Therefore many locals sometimes become reluctant to participate in interviews, in particular when few of the NGOs really come back and bring help to the communities. So there was always unpleasant feeling to approach the various families and ask questions about the tsunami, because they think they will receive aid. Likewise it felt difficult to ask the interviewee to bring back their memories during their escape from the tsunami. However, many of them were able to give a detailed description of their experiences. Due to time constraint, around 15 families were interviewed.
The advantage in this research is that one of the researchers speaks Acehnese. It was therefore easily to start a conversation with locals, since many of them stay either in front of their own homes or at the coffee house. Acehnese people are very talkative. Due that the interviews were carried out in Acehnese, it become much easier for them to express their story than with interviews carried out in English.

A starting question was “where were you during the tsunami strike,” following by a question on “how did you managed to survive.” From thereon the whole story about the various people’s escaping experience was told narratively. Therefore, most of the interviews activities consisted in to listen to the persons telling their stories while they were escaping the wave. Most answers were on how the locals got confused with the situation and started to follow the crowd expecting to find safer ground. Sometime the interviewees did not even know where the safer ground was. They fled in opposite direction of the wave towards the inland areas. Most of the interviewees expressed their inability to find an escape path in the segregated areas due to that a complex street network had slow down their escape flight.

During the panicking phase, the interviewees expressed that there was a moment where they could not clearly memorized the surroundings and therefore reduced the quality of their reaction. This is due to a lack of the preparation process and minimum knowledge about the behaviour of tsunami wave, such as from what direction it comes from, how it will hit the neighbourhood, and lack of knowledge on the location of safer place to escape. On the question on how the interviewees behave in a panic situation was that most of them fled in the opposite direction of the tsunami wave and they were following the crowds of fleeing people. It is in line with the research of Chu, Li and Zhao where the crowd probably followed some “natural born” leaders.

In some cases the question “what hold you in escaping the wave” had to be asked. Several people did not escape, because of a lack on knowledge on the effects of a tsunami. Almost all of the interviewed families admit that none of them had a decent understanding about tsunami and its effects when it happened in 2004. Others were concerned about their family members, such as children or old people, in which slowed their flight action. Several women with children expressed that there was confusion about the whole situation. It is due to the civil war in Aceh that within each community, women rarely leave their home in comparison to men. None of the interviewees could imagine that the wave could actually reach their homes, which is located around 3km away from the coastal line. Therefore many interviewees chose to stay at home, since they thought that water could not reach their houses. When the wave hit these local villages, it caused a tremendous panic situation.

Questions were asked about the number of family members affected by the tsunami, the number of tsunami victims in their villages and their opinion about as to why several people did not managed to escape. Several interviewees expressed that several people got trapped in their houses, due to that they did not escape in time from the wave. Others expressed that several people went back for helping children or elder people. Many interviewees expressed that they did not know where to run to since water came from several directions and they could not find a way out from the neighborhood due to a complicated street network. Several interviewees expressed that a lack of knowledge on the scale of the disaster and that a street net with many turns worsen the panic situation. This contributed to that many got trapped in the water.

Some questions about their thoughts about tsunami in the future were asked. Some interviewees believe that tsunami could strike again but not in a short period. Several locals estimated that a disaster of this kind might happen again in 50 to 100 years. Since the 2004 tsunami, Japan has helped Banda Aceh to set up
some escape buildings. Questions about these buildings usefulness and accessibility during a tsunami strikes were asked. The locals expressed that it depends on where the persons are located when a tsunami occurs. The interviewees expressed that a priority is to run to inland areas. If the escape building is on one’s escape route and the time and distance to a safer area is too long, these buildings will probably be used. The inland areas have probably priority for the interviewees due to that they were not hit by the 2004 tsunami.

Some of the inhabitants were unable to run to safer places due to a complex spatial structure of the street network in their neighbourhood. It is a typical spatial feature in those areas where the death rates was high. Some of the findings related to the street network are as follows:

- Some streets are short streets with a high number of turns. The junctions are messy and disorientating.
- The spatial hierarchy of the street network is not clear. The local streets are poorly accessible from the main routes in terms of a high number of direction changes. The street network inside a segregated village or neighbourhood is poorly connected to the rest of the city.
- Some area has high numbers of dead-end street that lead to a private property with high fences or to a cul-de-sac residential area.
- The high number of low-rise a building without any decent high landmark reduced the escape orientation. Inside the segregated villages there were no landmarks such as towers, hills or high-rise buildings that could function as an urban reference point for visual orientation.

These findings indicate that the outdoor quality of a neighbourhood influence the escape possibilities for its inhabitants. Figure 9 shows an example of a dead end street and a visually broken up street inside some of the segregated villages with high mortality rates.

*Figure 9: Images of dead end and broken up street network from area 2.*
5. DISCUSSION AND FUTURE PLANNING CHALLENGES

As the results from the Banda Aceh analyses shows, a network type of street grid is safer than a labyrinthy street grid in the case of human panic. It is not in line with the view of the tsunami engineers’ proposal for a tsunami safe city. From a perception psychological view, a network type of street grid is the safest in the case of panic, whereas from a technical perspective a labyrinthy street grid can break and reduce the wave force of tsunami. These two divergent views focus on two different issues. One is about water speed and the other is about human orientability. Therefore the challenge is to combine these two divergent views in urban planning practice.

A network street grid has high spatial integration values, whereas a labyrinthy street grid has low spatial integration values. Since the straight line street can be deadly in terms of producing high water speed, this street type has on the other hand high potentials as a main escape route through its high degree of orientability and short escape distance in comparison to the labyrinthy street net. However, a rigid structure such as a water wall, two or more storages building, etc. can somehow reduce the force of a tsunami wave.

Banda Aceh is a relatively small city, which has minimum financial ability. Therefore it is difficult to implement massive technical infrastructures such as tsunami walls or storm surge breakwater like in Japan and USA. Therefore, the following steps are proposed for improving the safety of Banda Aceh city:

Firstly, on a macro scale level is to make an integrated orientable street structure with a network structure. This includes removing all dead-end streets in the neighbourhood and to implement a visible main street network serving as a main escape route. The main escape route should directly head to the safety area such as a hill or higher areas. It has to be visible at the end of a main route. It is important to plan the street network in the neighbourhood level in such a way to reduce the number of direction changes toward an orientable main route heading towards a safety area.

Referring to human cognitive ability, people can easily memorize a neighbourhood within a range of 2 times direction changes. Beyond this requires more concentration and focus for way finding, in particular in panic situations where all kind of logical thinking gets lost. Therefore, in the case of a tsunami escape implies that planners need to locate crowded areas such as market places, shopping streets, etc, which has maximum 1-2 turns toward the safety location for effective tsunami fleet. Seemingly it is in line with research results on the location of successful shopping streets. A street of this kind tends to cover 80% of its neighbourhood within 2 times direction changes from it (van Nes, 2005).

Secondly, when a tsunami happens, the water will move from the shoreline to the urban fabric in a very short time. It starts with a water flow in the direction of perpendicular to the shoreline. How it change course or unfairly distribute it force toward other direction depend on the landscape’s shape and a city’s spatial structure. Having a street grid with streets perpendicular to the shoreline could be useful in the case of fleeing from a tsunami. It is the shortest way from the seashore to a safety area. However, this type of grid can trigger an urban block development that will have a channel-like shape at the street level. Here a tsunami can become more deadly and penetrate areas further into a city than when streets are horizontally located on a shore line.

Scattered urban block can be good in reducing the water force and provide dead trap for the watercourse. However, at the street level this scatter blocks tend to produce spatially segregated streets, which implies several turns for human beings before reaching the safety area. Therefore one proposal is to twist the street grid 45 degrees on the ocean’s direction. The streets are then not facing perpendicularly to the shoreline.
and can therefore reduce the wave force. Figure 10 shows a model on how a combination of the two divergent views can be implemented.

![Figure 10: Design principles macro scale Banda Aceh; Straight streets that are not perpendicular to a wave’s direction can make people flee easily and the building’s directions can also reduce tsunami force.](image)

Thirdly, for the planning of effective escape routes, straight lines seem to be un-avoidable. The straight line is effective as it produce the shortest distance to the target area. However, as discussed earlier, the straight line can be deadly because it increases a tsunami’s water speed. Furthermore, from the experience of tsunami 2004, the destroyed parts of Banda Aceh shows that most of the two storages buildings can withstand the force and survive the catastrophic wave. As indicated, the two storages buildings with reinforced concrete structure are strong enough to receive the water force and even reducing it.

The best for rebuilding Banda Aceh is to make an urban form that is both able to provide easy escape routes and to reduce the water speed. A planned straight street lines of escape routes need to be equipped with water speed reducing elements on the street level such as reinforced concrete pillar that tight together and form a rigid structure. This hollow structure will not disturb the fleet movement of the escaping people, but very useful in reducing the water speed of a tsunami wave. Therefore, this micro scale approach consists in target hardening of the built elements.

Fourthly, visible and orientable escape routes are the lifelines for the inhabitants. Therefore spatially highly integrated local main streets must have a spatial logic so that its inhabitants and visitors easily can understand them when escaping a tsunami. Due to that tsunami are rare events, these routes have to function on a daily basis as a vibrant route to produce a good cognitive map of the community for social and economic activities. Therefore, one urban design proposal could be to plan these routes as shopping streets that are highly integrated, well connected and visible to it surroundings.

Figure 11 shows some design principles on various scale levels on how to make a tsunami safe city. It consist in to twist the street grid 45 degrees on the coastal line, make orientable main routes with visible high places to escape to at its end, remove dead-end streets, make some visible landmarks along the main routes (such as towers or high buildings), and to target hardening all built up elements along the main routes for reducing the water speed.
A proposal was made in an MSc thesis on how this knowledge could be applied in Banda Aceh (figure 12). It implies adjustments of the various villages’ borders as well as to link all dead end streets to a connected network. The long main routes end on small hills or higher places. All the design principles presented in figure 11 were applied.
When analysing the proposed plan with a global integration analysis (figure 13), it has the potentials to become a new vibrant centre in Banda Aceh in addition to the old traditional colonial centre. The twisted network grid makes the proposal’s spatial structure topological shallow with few direction changes. Moreover, on a local scale (figure 14), the various local centres are well connected to the proposed main routes. This plan implies some adjustments on the existing property pattern. Anyway, it is at least an alternative solution on how to rebuild and to plan a tsunami safe city when the financial resources are few for building a large tsunami safe wall. Naturally, a cheaper solution would be to implement a warning system, escape signage system, and to train people inside each village to regularly inform the inhabitants to flee to higher ground in case of a tsunami. In case of cities with long time running civil wars, corruptions, and internal conflicts, the spatial structure of the street grid will function as a natural escape safety mechanism when implementing a warning system is difficult.

Even though there have been two large tsunami incidents in the world in 6 years, it is still a rare event. According to Eisner (2005), the probability of tsunami occurrence is less compared to other disaster. A tsunami is never recorded in Banda Aceh before 2004. Combined with the never-ending civil internal conflicts, Banda Aceh is and has been unprepared for managing major natural catastrophes. There exist no warning and signage systems and there was a total lack of trained ‘super agents’ or police who could tell people to flee to higher grounds. As a result, when tsunami hit Banda Aceh early in the morning, most of the inhabitants were unable to rely on others in escaping the threat. None of the government officers were on site to direct the evacuation flows.
Footage of tsunami 2004 and stories expressed by the communities show the human aspect was less contributing in escaping the wave. Therefore, it is believed in the Banda Aceh case that the spatial layout of the built environment played a significant role in peoples’ escape behavior in panic situations. The city infrastructures were not designed to stop or even minimize the risk of disaster. Structures such as tsunami walls or evacuation building are not available within the communities that are exposed to the danger. Therefore, for most of the areas near the coastline, a horizontal escape direction to the inland areas was the only option.

In evacuation situations, where the provision of ‘super agents’ is not reliable, the spatial properties of the built environment will play a significant role for the success of the effort. The analyses of Banda Aceh showed clearly that the highest mortality rated were found in extreme segregated streets adjacent but not accessible to integrated main routes.

Although some villages have some robust buildings of concrete (two storages houses) that were not swept away with the wave, buildings of this kind were used as evacuation building. In the segregated villages the spatial layout of the streets around these buildings area did not support the community to utilize the building as the evacuation area. Most of these two storages buildings are poorly integrated with its surrounding. Based on this evidence, the Banda Aceh case shows that the spatial structure of the street network matters to the success of the evacuation effort.

Figure 13: Global integration analysis of the proposal
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In this paper we would like to take a special moment to commemorate all the people who died in the 2004 and the recent 2011 tsunami, especially to all families and colleagues from Banda Aceh, Indonesia.

REFERENCES:


van Nes, Berghauser-Pont, Maschoodi, 2011, “Combination of Space Syntax with Spacematrix and the Mixed Use Index”, Proceedings 8th International Space Syntax Symposium, Santiago, Chile.


