A simulation study on fire evacuation routes in primary stage for a historic canal residential area

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Abstract

Nowadays, several previous studies have research about disaster emergency plan cause historic preservation areas are vulnerable to disasters rather than normal city area. The town of Khlong Bang Luang is a historic canal residential area, which is an old capital of Thailand in the past. This area is vulnerable to fire disaster. Because of the limited accessibility leads residents in this area to vulnerability for evacuate on emergency times. Furthermore, there are many wooden houses stand close, the narrow street between houses is inconvenient for evacuation and some of building materials are hazards to fire disaster. So this study proposes to simulate fire evacuation routes during emergency time by using applications to clarify the preparedness of the community planning for the best evacuation way. We hope that a guideline of multimodal evacuation will be provided based on the further study also in order to design architecture elements of the area.

1. Introduction

Most of the historic preservation areas are very vulnerable to disasters rather than typical city areas because of their particular issues; for example, wooden structures, narrow streets, and many vulnerable residents such as elders disable persons, etc. (Mishima et al.,2012) The areas have many problems like high dense wooden city areas, especially in the preservation area, narrow streets are also important elements should be preserved even if they have vulnerable to disaster risk (Mishima et al.,2014). Therefore, it is at least necessary to find effective measures of
evacuation for self-organize or mutual aid of the vulnerable people in such a historic preservation area. Fire disaster is one of hazard in dense urban area. Fire is a widespread phenomenon. It can have damaging economic and social effects, can spoil wood material, can burn down houses and historical element, and could be a cause of major casualties. There has been increasing publicity given. Most of the historic areas in Thailand have sparsely few fire protection systems. In addition, because of the need to protect the historic value, it is difficult to widen the narrow streets to prevent disaster. Thus, residents who live in the historic area may lack of crucial knowledge how to survive or evacuate on that time. Because of they may incapable to decide the best way for evacuation and the best destination to go through on that time. Therefore, appropriate guidelines about how to survive, vulnerable zone indicated and choices of evacuate routes may needed to mitigate disaster risk.

1.1. Aim of study

This study aims to find the element factors, designing architecture elements and planning evacuation routes that can help residents to survive when emergency event occurs in a historic canal residential area. We are considering to use multimodal access, which are the potentials of this site. There are community center and canals that can led residents to evacuate on emergency time However vulnerability must be conducted and implied before considering multimodal solution. In this study, vulnerable area from primary state of fire disaster will be studied to obtain essential results from GIS and realistic simulation applications.

1.2. Problem statement

Since the limited choice of evacuation route in this area is the most critical consideration. This study proposes to use multimodal access, which understudy by researchers. Multimodal access means to provides multiple access for evacuate on emergency time. Our model study area mentioned below is located in one of the historic canal residential area in which water is highly valuable and meaningful for residents. Also this area is one of the communities to be preserved as the valuable of their own area. Residents are operating their own business since settlement that not only to support there life while modernization comes to this area but their business also support cultural and represent traditional lifestyle in specific era of Thailand. Moreover, one of architecture in this area was selected by Association of Siamese Architect to conserve by using Vernadoc process (Vernacular architecture documentation).

However, this area is severe for fire situation because most of buildings made of wood and some houses are sharing architectural elements together. Although this area was equipped with fire protection system, the area is still vulnerable if residents are incapable to make decision where is safe place or which is the best evacuation route on panic time. Because the area is located close to canal, tourists use water transportation in the present. So this study would like to use the potential of canal to be an important route for evacuation on emergency times.

2. Method of study

2.1. Model study

The model study area is a historical town called “Khlong Bang Luang”, which located in Thonburi area. Which was a prosperous city in the past. Thonburi is an area of modern Bangkok located on the lowlands area. During the era of the kingdom of Ayutthaya, King Taksin established the kingdom of Thonburi in 1768. Thonburi was a capital until 1782. After that Bangkok was established in 1782 with the name of Rattanakosin. In Thonburi era, land along the canal determined by King to served for the nobleman’s residential area and also the canal has defensive function in the wartime. After Thonburi era collapse, Rattanakosin era was established. This era

Fig. 1. (a) Old canal; (b) New canal.
settlement features imitated the planning from Thonburi to opposite site of this area, which separated by Chao Praya River. The new settlement area had mirror the water feature character of Bangkok Yai canal. The canal or Khlong is the connecting route to the existing river (a ‘Khlong’ is a canal in Thai). These ‘Khlongs’ accommodated many social, cultural, commercial activities and it was also important for residents that lived near the waterway.

Study area located between the 2 districts: Bangkok Yai district (A) and Phasi Charoen (B) district. Canal is 6 kilometres long and performs as a public transport route in the traffic-congested capital and provide alternative to connect with capital city. So this area is the one of water community from past until now. Moreover, This area is located near Buddhist temple serves as a community area not only for religious ceremonies but also for public activities. Fig. 3. shows the temple that located near the canal and river. Most of temples always located along the intersection of canals and become the community centre for community. In this area, physical aspect is prone to fire and flood risk because resident’s evacuation routes are limit by its choices and narrowness which may lead to higher rate of mortalities when disaster occurs.

Fig. 2. (a) Building along canal; (b) Narrow Street in this area.

Fig. 3. Map of temples that located on the intersection of canal. The water features character of Thonburi.
2.2. Method of analysis

Methodology of this research aim to explore essential abstraction as following: literature study, site survey, problems of the site and also potential of this site in fire disaster approach. This research focus on the multimodal access in this area to provide evacuate in emergency time. Raw data was collected from site survey then input as GIS (Geographic Information System) data to clarify element factors that display as vulnerable and blockage area in this site. After vulnerable areas clarified, this research continues to simulation part that will use Pyrosim and FDS (Fire Dynamic Simulator) applications to compare between typical and panic situation. Then, the results of simulation will be discussed and concluded as new community disaster management. In further study, we will focus on multimodal access that represent viable new strategy and provide more potential than conventional method. Simulation scenarios will tested on this area. We will choose the best scenario for evacuate and urban design guideline for this area. Moreover, This research will show the primary results of this area about how to prepare, survive and evacuate on emergency times.

2.2.1 Analysis of vulnerable zone

In this research, we propose to determine the vulnerable zone. In this study GIS combine with fire disaster simulation application were chosen to display the result of vulnerable area and produce worst-case situation in simulation modeling. First, GIS application was used because GIS can show basic of statistic data and explain data in simple way. In term of simulation analysis, we use ‘Pyrosim’ to analyze worst-case situation by time of fire spread that we referred the result of primary vulnerable zone from GIS application. These applications are consist of:

- **ArcGIS**: is an application that related with geographic information system (GIS) for working with maps and geographic information. It is used for create a map, analyze mapping information, share and discover geographic information. On this research, Application will transform survey raw data into digital file and mapping. Moreover, this application will display factor element in this area and also vulnerable zone in primary stage.

- **Pyrosim and FDS**: is the leading software and graphical user interface for quickly and accurately working with Fire Dynamics Simulator (FDS). While most of models simulated by Pyrosim are indoor space used to imitate Fire and Smoke concerned with HVAC (Heat ventilation and air condition system) but on this research, we would like to use this application in urban scale by adjust and widen space of simulation with developed method, which may viable toolset to apply in further study.

The physical elements and factors on this site used ArcGIS application to analyse all data that collected form this site. From this study, we explain 4 elements that will effect to this area. There are building used, floor level, building condition and building material.
• Building level
Most of buildings level in this area is wooden house with 2 levels. While most of houses that along the canal are 1 level. Some of religious buildings are 1 level but height of each building more than 5 meters.

• Building condition
Most of buildings are in moderate condition. Some of houses which are historical building are in the deteriorate range. In near future, it is a must to considerate how to preserve and restructuring these buildings because they contain historical value and precious knowledge about this area in the past and in term of quality of life it will be increasing if we consider this factor. Well-being of resident is important thing that we must focus on this area.

• Building material
Most of building materials in this area are made from wood cause this area is historical area that many wooden house established in the past and still in use in present day. Concrete and wooden mix concrete is also used in this site especially religious building and some of modern house. From map fig.5, we can see that this area is vulnerable zone for fire situation because of many wooden houses were built closely together and some part of their houses are connect each other.

• Building use
Most of buildings used in this area are residential, religious building and mixed use. Moreover, there are 3 ports that still active and serve residents and tourists as alternative transportation. In term of community identity, water and temple community is the main characteristic of this site.

Fig. 5. (a) Building level; (b) Building condition; (c) Building material, (d) Building used.
2.2.2 Analysis of evacuation time

The main method of analysis in this study was to examine the evacuation routes from each house that located in the vulnerable zone to the designation safe place in the study area. We used applications for simulate the shortest and the lowest risk for evacuation routes by Pyrosim and FDS. Table 1 shows the weighted score of building elements factor in this area that concluded and analysed from GIS application, which could affect to fire spread.

| Material          | Score | Building |
|-------------------|-------|----------|
| Wood              | 4     | 90       |
| Concrete-Wood     | 3     | 55       |
| Concrete          | 2     | 59       |
| Etc.              | 1     | 28       |

| Condition         | Score | Building |
|-------------------|-------|----------|
| Deteriorate       | 3     | 11       |
| Moderate          | 2     | 88       |
| Good              | 1     | 123      |
| No data           | 0     | 10       |

| Level             | Score | Building |
|-------------------|-------|----------|
| 2 level           | 2     | 107      |
| 1 level           | 1     | 125      |

| Building used (Activity) | Score | Building |
|--------------------------|-------|----------|
| Mixed use                | 4     | 37       |
| Residential              | 3     | 137      |
| Etc.                     | 2     | 15       |
| Religious temple         | 1     | 33       |
| No data                  | 0     | 10       |

We evaluated vulnerable in this area from Table 1. High score to low score means factor that made vulnerable in this area. Then we used ArcGIS overlay method to combined building factors in Fig. 6. As follow: Blue building means low vulnerable building. Orange building means moderate vulnerable building and red building means high vulnerable building. Then, we used buffer method to represent fire spreading from vulnerable buildings in 5 meters radius. As showed on fig. 6. (a), light pink colour and dark pink colour means low fire spreading and high fire spreading. In fig. 6. (b) shows the buffer zone from canal into the residential area and it’s means advantage zone from canal. After overlaid 2 maps together, we found the area that is the most vulnerable zone and low vulnerable zone. There are 5 areas that have risk and limitation for evacuate when fire disaster occurs. Even though, some areas is not located on the dark pink zone but some of surrounding element that we show on analysis part can cause this area to become a risk zone. Vulnerable reasons and limitation on are as follows. Area (A) is located near the narrow street and intersection point. Some of houses near area (A) may collapse or burn up and blocked evacuate route on
emergency times. While this area is easy to connect to temple but residents can’t escape through to primary evacuation place cause many high vulnerable building located around this areas. Moreover, this area located far from canal. Area (B) is the area that located near canal but material of buildings around this area is wood. So it is vulnerable for fire spread. Area (C) is located near a temple and townhouses. Some of buildings in this area contain vulnerable condition and block by temple’s wall that has difficulty to access to the main street temporary safe place and primary evacuation place. Area (D) is located near canal but far from temple. Moreover, the walkway of riverfront has some architectural element that block resident to access canal. Area (E) is located in the opposite side of the river within narrow street. This area is near main street but narrow street and some architectural elements block this area and make it difficult to access to main Street.

Fig. 6. (a) Map of vulnerable zone, (b) The potential of canal, (c) Vulnerable area.

Table 2. Self-ignition temperatures of material (NIST)

| Material  | Ignite (Celsius) |
|-----------|-----------------|
| Wood      | 300             |
| Concrete  | 1200            |
| Steel     | 1450            |

From Table 2, we used these values to input and simulate with model of buildings on Pyrosim application. Then we selected areas A, B and E as origin of fire on application because of result of analysis by GIS moreover most of buildings around this area are wooden houses and also has historical building that preserve by Association of Siamese Architect. So this research propose to simulate and examine the viable evacuation time, fire spread, temperature and specific heat that will happen in 5 minutes on primary stage from each areas that located in the vulnerable zone.

3. Result and discussion

In this study, which targets the historic town area in Khlong Bang Luang are finding the vulnerable zone and the blockage area. By using element factors and site’s potential to analyze the vulnerable zone which could led to determination of the multimodal evacuation routes in further study.
Fig. 7. (a) Simulation of fire spread on 0 second; (b) Simulation of fire spread on 10 seconds, (c) Simulation of fire spread on 60 seconds, (d) Simulation of fire spread on 120 seconds, (e) Simulation of fire spread on 180 seconds, (f) Simulation of fire spread on 240 seconds.
Fig. 8. (a) The highest rate of fire spread simulation during 180 seconds.

Fig. 9. (a) HRR chart; (b) Burn rate chart.

We simulate the fire spread in this area by demonstrate temperature result. While temperature is a measure of the degree of molecular activity of a material compared to a reference point, Heat Release Rate (HRR) also used to demonstrate the rate at which fire releases energy. We set the time of fire spread in 5 minutes to investigate how fire could spread in time period. From Fig. 7., this is the result from Pyrosim application. We set 3 areas as origin of fire that we found from vulnerable analysis from GIS. During simulation time, fire is easy to spread to buildings that made from wood and buildings that have shared architecture elements. Also fire distinctively spread and block streets in this area as in Fig. 8. From 0 second to 10 seconds, fire is starting to spread to surrounding building. In 60 seconds, fire is spreading to the narrow street connected to canal. So (B) Street is the most vulnerable street in early 60 seconds. In 120 seconds, first intersection that located near the narrow street is the most vulnerable. So residents
unable to evacuate direct to this area after 120 seconds pass. While area c, residents who adjacent stay at this area able to evacuate direct to Main Street or canal. Between 120 seconds to 180 seconds, second intersection point is becoming vulnerable zone moreover HRR and burn rate that refer with Fig. 9. become the highest rate in this range. After 180 seconds, fire is spread over in this area.

Here, we should mention the limitations of this study. Elements factors that showed on this paper are result from survey data. During we were surveying in this area, some of building still renovating and destroying to become a new building. Most of building material made from wood. Thus, we can understand this area that is easy for fire spread. Furthermore, Most of building usage are residential type and may find accessible difficulty. Some of residential shared the same access to their accommodation because they are relative family. So this increase difficulty for evacuation when fire disaster occurred. Moreover, Public Streets are narrow and block by some of architecture element and being use as parking space. Residents may find difficulty to escape through to temporary safe place or another area.

Lastly, this study was an exploratory survey that can be referred and showed the results of high vulnerable zone and blockage zone in primary stage. A another area, which is same character of this area can follows the methods of this study to be a guideline for finding element factor that can effect to their own area.

4. Conclusion

Recently, Khlong Bang Luang is an old historical town that basically initiates a fire emergency system. But in term of architecture and urban design is the one factor that could improve this area by designing, planning and increasing well being of people in this area to live with their traditional way and modern life on fire emergency times.

In this study, the result provided essential data for primary state of vulnerable analysis. We found many results that distinctively effect and also time estimation of fire disaster. From this study, we focus on the physical issues consist of building use, building material, building area, building condition and building level conform with the advantage of this site and simulate vulnerable areas with applications. So the results of this analysis provide better understanding in canal community’s current situation and fire risk condition. Elements factor also represent important issue for residents to comprehend the vulnerable and blockage zone. This study also imply that residents must concern and realize the evacuation route in this area which route is the most severe than another area to avoid casualty. We will continue to further research by using this study as the one factor that can clarified the vulnerable zone to simulate another area with applications and find the best solution for evacuate on fire emergency time as multimodal access. Furthermore, this research, aim to provide appropriate guideline for living in this area by architectural elements design, determining safety zone and so on.

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