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The Assessment of Site Design as a Passive Fire Protection System in Traditional Batak Toba Settlements, Kampung Ulos Hutaraja-Pardamean

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Abstract The fire protection system is divided into two, active and passive. Passive fire protection systems are more reliable than active fire protection systems. In passive fire protection, site design is an important aspect. The site design has several indicators, namely the presence of water sources, the distance between buildings, the arrangement of mass blocks, the availability of open space, and the presence of flammable objects. Almost all settlements of the traditional houses in Indonesia, including Batak Toba houses, are very vulnerable to fire hazards. This research aims to find site design elements as passive fire protection variables and assess the reliability of site design as a passive protection system in the Kampung Ulos Hutaraja-Pardamean. The Interviews and observations data were collected through direct observation of researchers on-site involving safety experts, primarily passive protection, Residential and Batak Toba traditional house-building experts, Indigenous Peoples, and the Fire Department. The data analysis method uses the Analytic Hierarchy Process (AHP) method. The AHP method shows the magnitude of the role of each indicator in achieving the level of site design reliability in passive protection systems. After finding the hierarchical order, the next step is to assess the reliability of the site design as a passive protection system. The reliability of the passive protection system in the site design is 67.085%, which means that the reliability condition is quite good but still needs to be optimized. Among the five Site Design variables, building distance is the most influential variable on the passive fire protection system of Toba Batak Traditional House. It has a hierarchy value of 51.04%, which means a significant impact will occur if optimization efforts are carried out on the distance variable between buildings compared to other variables.

Keywords Passive Protection System, Site Design, Traditional Settlements

1. Introduction

Among various types of disasters, fire is a significant threat to life and property in urban and rural areas [1]. Fire hazards are usually considered as factors that cause fires to occur, accelerate the spread and worsen the damage caused by fire. They may be related to the environment, building structure, and building content, as well as human activities [2].

Fire occurs as a fire triangle reaction, namely the reaction of flammable materials/oxygen fuel and heat. According to the location, fires are divided into 4 (four), namely residential fires, industrial fires, transportation fires and forest fires [3]. Most fires occur due to short circuits. An electrical short circuit is caused by connecting the positive conductor to the negative conductor, resulting in a short circuit. This short circuit produces very short heat energy, causing an explosion and can burn anything in a short time [4].

When a fire occurs, four things need to be considered regarding the danger of fire: building occupants (people), building contents (property), building structure, and adjacent buildings. The first three things relate to the danger of fire in burning buildings, while the last thing is a consideration for other buildings and the community environment as a whole [5].

Therefore, a fire risk analysis is needed. The goal of building fire risk analysis is to gain insight into and characterize fire-related risks to better inform the various decisions that must be made as part of the design, construction, and operation of buildings [6].

In the case of architectural heritage sites, several hazard risks may also threaten these sites, such as earthquakes, fires, and floods. However, among the various risk factors, the risk of fire hazards can have the most dramatic effect on architectural heritage sites. If a fire breaks out, it can spread quickly depending on strong winds and become destructive before firefighters reach the location. Once the fire spreads, destroying entire sites with traditional housing and life within them becomes inevitable [7]. Fires can cause major losses not only to property, business continuity, and the environment but also to the cultural heritage within [6].

In the preservation of historic sites and the traditional buildings within them, the overall goal of fire prevention is to preserve that heritage both from the negative effects of fire and from the implementation of fire prevention measures that damage the originality of the structure. At historic sites with a high risk of fire danger, strategies must be provided to prevent fires from spreading [7].

The challenge in protecting cultural heritage settlements, such as Traditional House buildings, is maintaining the historic structure while providing a reasonable level of security for the occupants and contents. To avoid damage to the historic character of buildings, architects and planners must have a sensitive and ingenious approach to provide fire prevention and protection measures that do not damage historic building structures [8]. In this case, the need to preserve the authenticity of historic buildings usually leads to expensive fire safety solutions because the implementation of fire protection systems uses the latest technology and materials [9].

Protection systems need to be included in buildings and are an obligation to provide, especially for public facility buildings and buildings that accommodate large numbers of people. In its implementation, the arrangement or planning must be involved continuously during the entire construction process. The construction process is the planning, design, construction, operation repair, and maintenance stages. In general, there are two known fire prevention systems: active protection systems and passive protection systems. In principle, fighting fires prioritizes passive protection efforts first, then active protection efforts to deal with fires. When operational, these two systems handle fires together [10].

In the context of Toba Batak's traditional settlements, there have been several fires that occurred both in traditional houses and their surroundings. Settlements filled with historic buildings dominated by wooden materials are generally vulnerable to fire [11]. Based on statistics collected by the author regarding fire incidents in the last ten years, there have been many incidents of burning of traditional house settlements in Indonesia. Almost all Traditional House villages/settlements (including many incidents experienced in Toba Batak Houses) are vulnerable to fire. Most building fires are caused by unknown factors, followed by electricity, natural events (lightning, drought), and human negligence.

Apart from that, traditional Batak house construction also uses wood with a low water content because it is more resistant to weather changes and does not expand and shrink easily. Wood with specifications like this is used for most construction elements, such as doors, windows, frames, floorboards, and roof construction. Based on research, dry wood material is very flammable if exposed to fire [12]. Because wood-based construction itself is an element that can contribute significantly to the growth of fire and simultaneously result in increased combustion against poisoning arising from increased carbon monoxide production [13][14][15][16][12].

In response to those cases, it is necessary to carry out a comprehensive study regarding the level of reliability of the passive fire protection system in the Toba Batak Traditional Settlement, Kampung Ulos Hutaraja-Pardamean in Pangururan District, Samosir Regency, North Sumatra Province. It is chosen because there are still Toba Batak Traditional Houses or Gorga Houses, whose authenticity is still maintained [17]. So that the risk of fire can be reduced. This is an effort to overcome fire, one of the main threats to the existence of Toba Batak Traditional Settlements.

Therefore, this research aims to study site design as a passive fire protection system in traditional Batak Toba settlements. The mixed method is used in this research. The research was carried out by collecting primary and secondary data. Primary data was obtained through direct observation and in-depth interviews. Data collection was carried out through direct field observations of the existing conditions of the site design in Kampung Ulos Hutaraja-Pardamean and in-depth interviews involving 12 resource persons, including Firesafety Experts, especially passive protection, Toba Batak traditional settlement and house building experts, local community, and the Fire Department Authority. Meanwhile, secondary data was obtained from the literature review. Next, the data was analyzed using the Analytic Hierarchy Process (AHP) method and ordinal scale. The AHP method shows the magnitude of the role of each indicator in achieving the level of site design reliability in passive protection systems.

After finding the hierarchical order, the reliability of the site design for the passive protection system is assessed using an ordinal scale by the experts.

2. Materials and Methods

2.1. Passive Fire Protection System

The passive fire protection system is the ability of the structure stability, construction resistance, compartmentalization, and separation, as well as protection in existing openings to restrain and limit the speed of fire spread [5]. Passive measures can provide adequate fire protection for building construction elements. They are intended to limit the fire within its origin without affecting the surrounding area. The spreads slowed down through protected compartments, corridors, lobbies, and stairwells. The building structure has to withstand fire for some time so that occupants can evacuate [18].

In principle, fire prevention is prioritized on passive protection systems first and then carry out active protection systems to deal with fires [10]. In addition, passive protection systems have high efficiency and durability and minimum inspection and maintenance. In the construction industry, passive protection systems are one of the most practical ways to increase the fire resistance of structures [19]. Passive fire protection is usually preferred over active fire protection systems due to the inherent safety without additional intervention through manual means or detection and control systems that may malfunction or be disrupted due to the incident. Main passive measures include distancing and installing protective barriers, limiting fuel sources, and utilizing less hazardous processes [20].

The variables of the passive protection systems are site planning and design, access, and building environment [10]. Also, it states that setting the site plan is included in the passive protection system [21].

2.1.1. Site Design

Site planning is the regulation of the building site, including building layout and orientation, distance between buildings, placement of hydrants, provision of open spaces, and so on, to prevent and minimize fire hazards [22]. In site planning and design, access, and building environment, some of the things that are included in the site problems concerning fire prevention include the arrangement of residential mass blocks and the distance between buildings, the access to residential and building environments, the availability of parking areas or open space, providing exterior hydrants in area environment and providing flow and water supply capacity for blackouts [10].

In the event of fires, fire can spread from one building to another if the buildings are within a sufficiently close distance, mainly due to radiant heat transfer and direct emission of flames. In general, the closer a residence is to the source of fire, the faster a fire will occur in that residence. However, there are other factors, such as the heat flux that happens, the orientation of the place towards the fire, and the direction of the wind when the fire occurs. Several small fires develop into major fires due to the layout of the settlement. This is viewed as structural conditions, namely the high risk of a large fire in a settlement if the residence is close enough to at least one neighbor to accelerate the fire spread, especially if the location is close enough for direct sparks [23].

Separating blocks aims to localize fire so that it does not easily spread to other buildings and separate groups of buildings with a high fire risk from buildings with a low fire risk [24]. Form of settlements may have influenced the impact of the fires. When the fire reaches a sufficient limit, the spread will stop. Suitable boundaries may be determined by obstructions such as roads or clearings. An obvious concern is that as housing grows and density increases, more housing will move into the high-risk transition zone. Improving the layout of settlements will be very important to slow the spread of fire. However, implementing them may be difficult given that the mapping is being carried out in existing settlements, and a significant shift to the housing sector will require the displacement of large numbers of residents. The layout of informal settlements plays a substantial role in determining the speed at which fires spread from small-scale to large-scale fires [23].

The construction process that prioritizes the speed of construction often causes the building to be built without carefully considering its safety. This condition causes the ward-level area to continue to face serious problems such as messy building growth, traffic jams, poor spatial planning, inadequate infrastructure, lack of open space, environmental damage, and increased vulnerability to fire hazards. This condition is exacerbated by an increase in population density, which also leads to an increase in building density, an increase in mixed land use plots, a decrease in open space, and a reduction in the effective width of roads. In short, there is a decrease in open space and adequate traffic lanes at the regional level due to an increase in plot coverage and built-up land area in an area [25].

A residential area can be vulnerable to fire risk due to location, average wind speed, settlement patterns, and building characteristics. Therefore, it is necessary to take preventive measures against fire occurred. The cause of the increased fire hazard risk in land use planning is the lack of an automatic containment system in buildings. The distance between buildings that are too close is also a risk factor that causes the fire to spread faster. Limited access route options to buildings and narrow road conditions are other risk factors that must be considered in fire safety planning because they can hinder the rescue process. The position of electricity poles that are too close to traditional houses is a risk factor for fire [7].

The spread of fire due to fire can be seen when the fire conditions have enlarged. It often happens between a house on fire and an adjacent place or even next door where the fire that appears in the next home is not realized because the view is closed in the big fire of the first burning house [26]. In addition, based on the results of previous research, it has also been proven that fires occurred in the area. The village's cultural heritage will immediately extend to adjacent houses because the houses are built with wooden structures [27].

Based on Table 1, several previous studies have conducted research related to site design. From this study, several indicators are suitable for use, namely the presence of water sources, the distance between buildings, the arrangement of mass blocks, the availability of open space, and the presence of flammable objects.

Table 1. Site Design on Passive Protection System for Traditional Settlements

References	Factors
Stevens et al., 2020	• Settlement layout • Building distance • Building density
Xia et al., 2019	• Space patterns • Land use
Himoto et al., 2018	• Large open area • Distance between buildings
Kumar et al., 2018	• Site plan open space
Sun- gyu et al., 2014	• Building distance • Protection of construction materials
Durak et al., 2011	• Effective distance between buildings • Availability of water in the area environment
Permen Pu No.26 Prtm, 2008	• Arrangement of mass building blocks • Effective distance between buildings • Availability of parking area or open space in the environment area • Availability of water in the environment area
Rahman, Vinky 2003	• Mob block arrangement • Distance between buildings • Open Space availability • Presence water source

2.2. Research Approach

The method applied in this research is a mixed method. Mixed methods are a combination of two forms of qualitative research approaches and a form of quantitative research approach. The research objectives use qualitative and quantitative methods to obtain more comprehensive, valid, reliable, and objective data [28] [29].

In the first stage, the qualitative method collects the constructs of question items, and statements will become the basis for developing research instruments. The data obtained through interviews and observations aimed at uncovering personality characteristics and phenomena are the forerunners of the preparation of quantitative instruments. The second stage is carried out after the results of the first stage are obtained. The results are processed again using quantitative methods. At this stage, testing the validity and reliability of the instrument will be carried out.

The research started by collecting primary data obtained from observations and deep interviews, as well as secondary data obtained from literature reviews. Data from deep interviews and literature studies were analyzed using the AHP method to obtain a hierarchy of variables and indicators. Then, an assessment was carried out of the reliability value of the site design as passive protection in existing conditions based on data from observations, deep interviews, and hierarchical values (Figure 1).

2.3. Data Collection

Data was collected through observation and in-depth interviews. Observations are carried out by observing and measuring physical conditions in the field and interviews with several participants who met the selection criteria to answer the formulation of the problem regarding the reliability of passive fire protection systems in the existing conditions of Batak Toba traditional settlements. The next step is to describe the observation activities carried out on each item. Interviews were conducted with several informants with the previously predetermined criteria.

In this study, the determination of informants was carried out using a purposive sampling technique. This technique applies sampling to data sources considering certain characteristics following the research objectives with a list of characteristics compiled referring to previous similar studies. These particular considerations, for example, are sources who are considered to know the most (experts) about what is being researched, or maybe he is a person who masters the field/topic so that it will make it easier for researchers to explore the object under study [29].

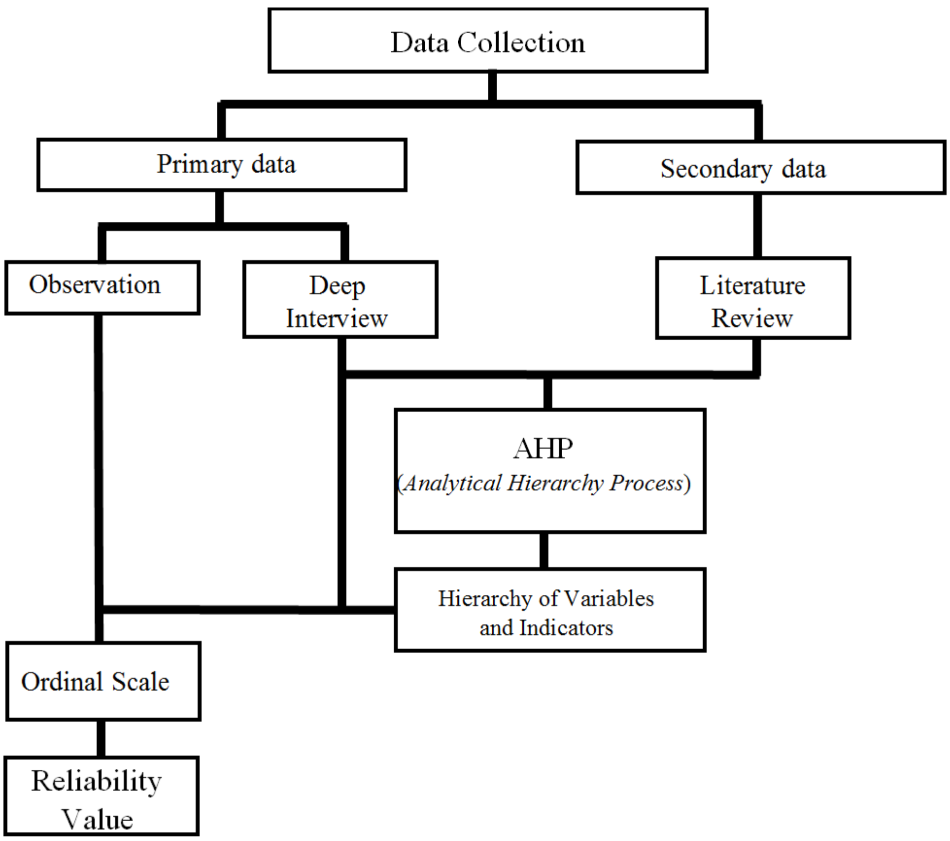


Figure 1. Methodological Framework

Referring to the purposive technique with consideration of previous citations in similar research, the criteria for informants used were:

1. Expert in the field of Fire and Fire Protection Systems
2. Expert in identifying Batak Toba Traditional Houses in terms of architecture.
3. Sources with related experience to fire incidents in Batak Toba Traditional Settlements.

After knowing the required sources and their numbers, the next step is to compile questions to answer the problem formulation according to the variables with the indicators that have been determined. The questions on the interview will use a deep interview process. After obtaining data regarding the existing conditions, data collection is carried out in the form of an expert's assessment of the current conditions. Data in the form of values will be collected using the Likert theory ordinal scale method.

2.4. Participant

Data were collected through observation and in-depth interviews. Observations are carried out by observing and measuring physical conditions in the field. In-depth interviews were conducted with 12 sources, including 2 Firesafety Experts, especially passive protection, 2 Toba Batak traditional settlement and house building experts, 4 local communities in Kampung Ulos Hutaraja-Pardamean, local communities whose houses had burned down, and 2 Fire Department Authorities. The sources were determined using the purposive sampling method. The question list consists of structured questions and unstructured questions (Table 2). Unstructured questions were conducted with all sources, starting from fire safety experts, Traditional Batak Toba settlement and house building experts, local communities in Kampung Ulos Hutaraja-Pardamean, local communities whose houses had burned down, and firefighting authorities to determine the hierarchy of indicators and variables and collect existing conditions data. Meanwhile, structured questions are only conducted with fire safety experts to assess existing conditions based on previously collected data.

Table 2. List of Questions

Unstructured Questions		
No.	Sources	Questions
1.	Fire safety experts	What is the intensity of interest between design site variables and indicators in forming passive protection?
		What is the reliability of the existing conditions of the site design as a passive fire protection system?
2.	Traditional Batak Toba settlements and house-building experts	What are the distinctive characteristics of Toba Batak's traditional houses and buildings?
3.	local community	What are the existing conditions of the Toba Batak traditional settlements they inhabit?
		What is the physical condition of the Toba Batak traditional house they live in?
4.	local community affected by fire	What is the chronology of fires that have occurred?
5.	fire authorities	How are fire prevention efforts carried out?
		What firefighting facilities are currently available?
Structured Questions		
No.	Sources	Questions
1.	Fire safety experts	What is the reliability of the distance to the front of the building in existing conditions regarding passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of the side distance of the building in existing conditions in terms of passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of water source capacity under existing conditions in terms of passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of the water source distance under existing conditions in terms of passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of open space in existing conditions in terms of passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of open space surface conditions in existing conditions regarding passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of the mass arrangement in the site under existing conditions regarding passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of the position of the building mass relative to the road in existing conditions in terms of passive protection systems? Is it awful/bad/good/perfect?
		How does the reliability of laying flammable objects transfer to existing conditions in terms of passive protection systems? Is it awful/bad/good/perfect?
		What is the reliability of placing immovable flammable objects in existing conditions regarding passive protection systems? Is it awful/bad/good/perfect?

2.5. Data Analysis Methods

The data analysis method was carried out based on research objectives, namely evaluating passive fire protection in Traditional Batak Toba Housing, determining optional passive fire protection alternatives that could be applied to Traditional Batak Toba Housing, and then obtaining the optimal solution for passive fire protection for Traditional Batak Toba Settlements. To evaluate the reliability of passive fire protection of existing buildings, the Analytic Hierarchy Process (AHP) method was used to analyze the decision-making.

In the early stages, research variable data were used as input data for the Analytic Hierarchy Process (AHP) method. The procedural steps are to create hierarchical weights on research variables and evaluate criteria and alternative variables. The analytical data were obtained from secondary data (through a literature review). The analytical data were tested based on primary data (through field observations), and data from in-depth interviews with informants.

The data obtained from the results of evaluating the reliability of aspects of passive fire protection in the existing case are used as a database to determine or make a decision on which interception aspects of passive fire protection alternatives can be applied to Traditional Batak Toba Settlements. In this case, 3 (three) data sources, namely observation data, literature references, and interview data, are also used as the basis for decision-making analysis.

Evaluation of passive fire protection uses the Analytic Hierarchy Process (AHP) method to obtain the performance of each of the passive fire protection aspects of the study object, as well as the total results of the overall evaluation of the research object's passive fire protection. Furthermore, based on the results of evaluation research on existing passive fire protection, and data sources (observations, literature, and informants), alternatives to passive fire protection were analyzed for the object of study, to then make the results of passive fire protection planning for Traditional Batak Toba Traditional Settlements.

2.5.1. Stages of the AHP Method

The AHP analysis method is carried out through several stages. The first stage is an assessment by experts. The expert assigns a value to each variable compared to other variables. The second step is synthesis. At this step, the sum of the scores of each column in the matrix. Then, divide each score in the queue by the total value of the column in question. This stage aims to obtain matrix normalization. Then, the score of each row is summed and divided by the number of elements to get an average value. The average value is used to rank the variable hierarchies.

After all these values are obtained, all the indicators of hierarchical values are searched for all variables. The hierarchical value of all hands is obtained by multiplying the average value of the indicators and hierarchical variables and then dividing by 100% (Figure 2).

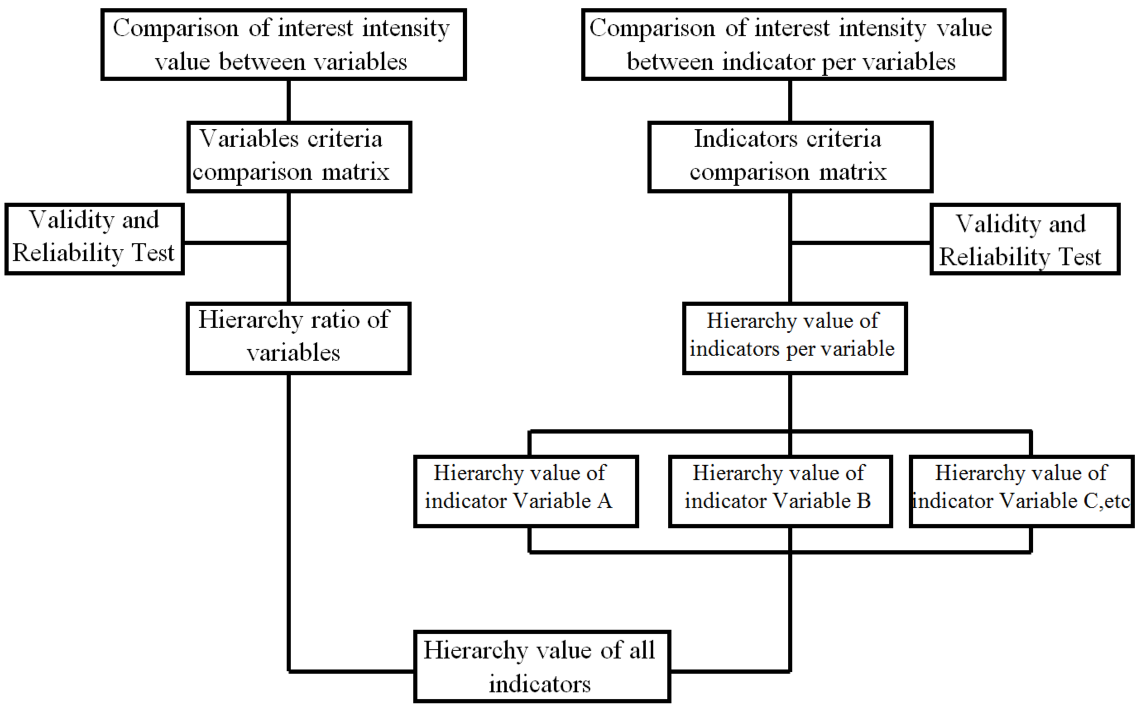


Figure 2. Stages of the AHP Method

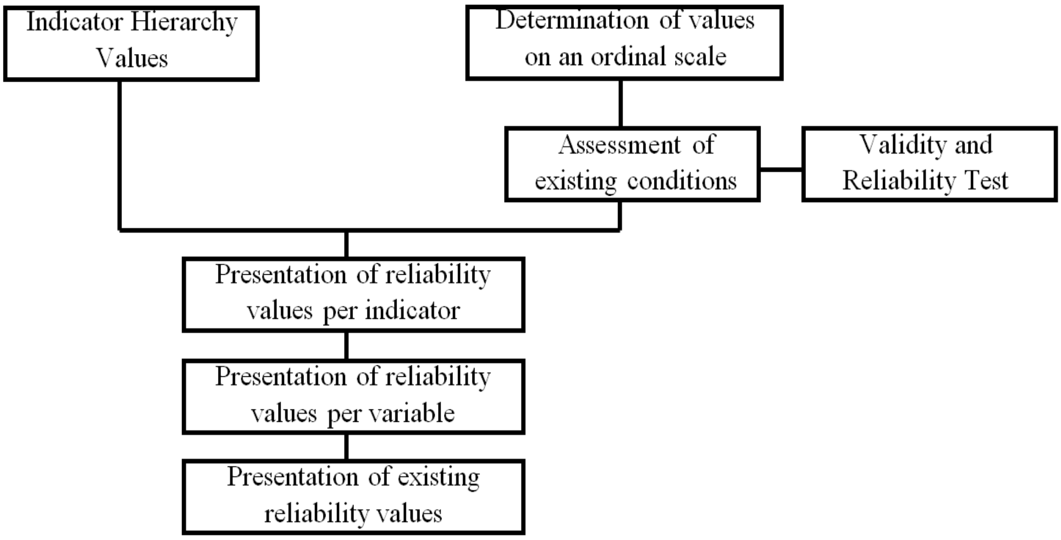


Figure 3. Stages of the Assessment with Ordinal Scale

2.5.2. Stages of the Ordinal Scale

Next is the processing of ordinal scale data. On the ordinal scale, data is obtained as numbers, the values of indicators and variables. These values cannot stand alone because the importance of each variable or indicator has different weights according to the hierarchy of the indicators or variables. The intended result is the ratio of existing values of each variable and indicator to the rate of existing passive fire protection achievement levels.

The ordinal scale used ranks the level from the low value to the high value. These criteria are used by experts in providing scores to the existing conditions. If the conditions are very bad, variables do not exist/are at very high risk / need significant improvement, then the score is 1. If the conditions are bad, variables exist but do not work according to the eligibility standard / medium-high risk; the score is 2. If the condition is good, the variables exist, and meet the standard but can still be improved/low risk, then the score is 3. If the condition is very good, it means the variables are considered very good/perfectly works; then the score is 4.

The values from the ordinal scale data are then translated into existing reliability values. The existing reliability value is processed into a ratio of the current reliability indicator value with the formula:

$$\text{Ratio of existing indicator reliability values} = \frac{(existing\ \ reliability\ \ value)}{(4\ \times\ number\ \ of\ \ parameter)} \times 100\%$$

Four is the maximum value per parameter that can be achieved.

After getting the ratio of the reliability value of the existing indicators, the next step is to find the ratio of the existing indicator values using the formula:

Ratio of existing indicator values = (ratio of existing indicator reliability values × Indicator Priority Hierarchy)

Next is to get the ratio value of the existing variable. The ratio value of the current variable is the result of the sum of the ratio values of the current indicators. Meanwhile, to obtain the ratio of the existing passive fire protection achievement level for each variable, divide the existing variable's ratio value by the variable's hierarchical value (Figure 3).

2.6. Data Validity and Reliability

2.6.1. Data Validity and Reliability of the AHP Method

However, it is necessary to carry out several more testing steps to ensure the validity of the values obtained. The first test step is to add up all the values in the average row. The matrix is valid if the result score is 1. The second testing step is to measure the consistency of the assessment. The maximum value of the consistency ratio is ≤ 0.1. The steps for testing the thickness of the evaluation are first by multiplying each value in the first column with the relative priority of the first element, the value in the second element with the comparable focus of the second element, and so on. The second step is adding up each row. The sum of the rows is then divided by the relevant relative priority element. The sum of the quotient with the number of resulting factors is called I max.

After carrying out these steps, the next step is to carry out consistency ratio.

Consistency index formula:

CI = (Lamda max-n)/(n-1)

Consistency ratio formula:

CR=CI/IR

Annotation:
CR = Consistency Ratio,
CI = Consistency Index
IR = Index Random Consistency

Table 3. Index Random Consistency

n	IR
1	0
2	0
3	0,58
4	0,9
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49
11	1,51
12	1,48
13	1,56
14	1,57
15	1,59

If the results are ≤ 0.1, then the results of the analysis using the AHP method can be said to be consistent and valid (Table 3).

2.6.2. Data Validity and Reliability of the Ordinal Scale

For a measuring instrument or an instrument that will be carried out for research to become an acceptable or standard measuring instrument, the instrument must go through a validity and reliability test of the data. Validity testing, according to expert opinion, can use the Pearson product-moment formula, and then after that, it is tested using a test. t, and after that, we look at the interpretation of the correlation index [30].

$$\text{r count} = \frac{n(\sum XY)-(\sum X).(\sum Y)}{\sqrt{\{n.\sum X^2-(\sum X)^2\}.\{n.\sum Y^2-(\sum Y)^2\}}}$$

Annotation:

r count = Correlation coefficient
ΣXi = Total item scores
ΣYi = Total score (items)
n = Number of respondents
Formula: t testz

$$\text{t count: } \frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}}$$

For table t α = 0.05 degrees of freedom (dk = n-2)

If t count > t table means it is valid and vice versa, t count < t table is not valid; if the instrument is valid, then the correlation index (r) is as follows:

0.800 - 1.000: Very high
0.600 - 0.799: High
0.400 - 0.599: Quite high
0.200 - 0.399: Low
0.000 - 0.199: Very low or invalid

3. Results

3.1. AHP Result

3.1.1. Comparison of Hierarchical Values between Indicators on Site Design Variables

The AHP method is used to determine the hierarchical value, which describes the percentage of the role of a variable and indicator on the reliability of site design as a passive fire protection system in Traditional Batak Toba Settlements. The results from this method were then ranked from the most impactful to the least impactful. The following is an expert assessment based on the existing condition of the passive fire protection system in Kampung Ulos Hutaraja-Pardamean.

Table 4 shows a comparison of intensity values between site design variables. This assessment is carried out by experts. The data obtained from this assessment is then entered into the criteria comparison matrix table.

Based on Table 5, a priority hierarchy is obtained between site design variables for passive fire protection systems in Traditional Batak Toba Settlements. The water source has a hierarchical value of 0.221, the distance between buildings has a hierarchical value of 0.514, the arrangement of mass blocks has a hierarchical value of 0.067, open space has a hierarchical value of 0.132, and the presence of flammable objects has a hierarchical value of 0.065.

Table 4. Comparison of Interest Intensity Values Between Site Design Variables in Passive Protection System for Traditional Batak Toba Traditional Settlements

Intensity of Interest	1	2	3	4	5	6	7	8	9	9	8	7	6	5	4	3	2	1	
Mass Block Arrangement																			Open Space
Mass Block Arrangement																			Presence of flammable objects
Water Sources																			Distance Between Buildings
Water Sources																			Mass Block Arrangement
Water Sources																			Open Space
Water Sources																			Existence object easy burnt
Distance between Buildings																			Mass Block Arrangement
Distance between Buildings																			Open Space
Distance between Buildings																			Existence flammable object
Open Space																			Presence of flammable objects

Table 5. Matrix Comparison Criteria

Criteria	Water Source	Building Distance	Mass Block Arrangement	Open Space	Presence of Flammable Object	Eigen values					Amount	Average
Mass Block Arrangement	0.5	0.2	1	0.333	1	0.071	0.083	0.038	0.038	0.038	0.336	0.067
Water Sources	1	0.2	2	3	4	0.141	0.105	0.167	0.346	0.346	1.105	0.221
Building Distance	5	1	5	4	4	0.706	0.526	0.462	0.462	0.462	2,572	0.514
Open Space	0.333	0.25	3	1	3	0.047	0.25	0.115	0.115	0.115	0.659	0.132
Presence of Flammable Object	0.25	0.25	1	0.333	1	0.035	0.083	0.038	0.038	0.038	0.327	0.065
Amount	7,083	19	12	8,667	13							1

Table 6. Consistency Test

Lamda Max	=	(7.083x 0.221)+(1.9x0.514)+(12x0.0067)+(8.667x0.132)+(13x0.065)	=	5.34351
CI	=	(5.34351-5) /(5-1)	=	0.08588
CR	=	(0.08588/1.12)	=	0.07668

Table 7. Hierarchy Ratio in Site Design Variables

Variables	Hierarchy
Mass Block Arrangement	6.7 %
Building Distance	51.4 %
Water Sources	22.1 %
Open Space	13.2 %
Presence of Flammable Object	6.5 %

Table 8. Comparison of Interest Intensity Values Between Indicators of Mass Block Arrangement in the Passive Fire Protection System for Traditional Batak Toba Traditional Settlements

Intensity of Interest	1	2	3	4	5	6	7	8	9	9	8	7	6	5	4	3	2	1	
Mass Arrangement in Site																			Position of the Mass relative to the road

Table 9. Criteria Comparison Matrix

Criteria	Left-Right Side	Front side	Eigen values		Amount	Average
Mass Arrangement in Site	1,000	7,000	0.875	0.875	1,750	0.875
Position of the Mass relative to the road	0.143	1,000	0.125	0.125	0.250	0.125
Amount	1.143	8,000				

Table 10. Consistency Test

Lamda Max	=	(1.143x 0.875)+(8x0.125)	=	2
CI	=	(2-2) /(2-1)	=	0
CR	=	(0/0)	=	0.0

Table 6 serves to test the validity and reliability of the data. As in Sub-chapter 2.6.1 concerning the stages of the analysis method with AHP, the results are consistent and valid if the CR or consistency ratio results are ≤ 0.1. From Table 6, the CR results are 0.07668. Then, the hierarchical results obtained in Table 6 can be declared valid.

Table 7 summarises the ratio comparison of hierarchical values between passive protection system site design variables based on the AHP method. The results obtained are that the building distance indicator has the highest ratio with a ratio of 51.4%, then overall sequentially to the lowest are water sources with a ratio of 22.1%, open space with a ratio of 13.2%, arrangement of mass blocks with a balance of 6.7%, and lastly, the presence of flammable objects with a ratio of 6.5.

A. Comparison of Hierarchical Values between Indicators in Mass Block Arrangement Variable

Table 8 comparison of intensity values between parameters on mass block arrangement indicators. This assessment is carried out by experts. The data obtained from this assessment is then entered into the criteria comparison matrix table.

Based on Table 9, a priority hierarchy is obtained between the parameter indicators for the mass block arrangement of passive fire protection systems in traditional Batak Toba houses. The mass composition on the site has a hierarchical value of 0.875 and the mass position on the road has a hierarchical value of 0.125.

Table 10 serves to test the validity and reliability of the data. As in Sub-chapter 2.6.1 concerning the stages of the analysis method with AHP, the results are stated to be consistent and valid if the CR or consistency ratio results are ≤ 0.1. From Table 10, the CR results are 0.0. Then the hierarchical results obtained in Table 10 can be declared valid.

Table 11. Hierarchy Ratio in the Mass Block Arrangement Indicator

Indicators	Hierarchy
Mass Arrangement in Site	87.5 %
Position of the Mass relative to the road	12.5 %

Table 12. Comparison of Interest Intensity Values between Indicators of Water Sources in Passive Fire Protection Systems for Batak Toba Traditional Houses

Intensity of Interest	1	2	3	4	5	6	7	8	9	9	8	7	6	5	4	3	2	1	
Capacity																			Distance

Table 13. Criteria Comparison Matrix

Criteria	Capacity	Distance	Eigen values		Amount	Average
Capacity	1,000	0.250	0.200	0.200	0.400	0.200
Distance	4,000	1,000	0.800	0.800	1,600	0.800
Amount	5,000	1,250				

Table 14. Consistency Test

Lamda Max	=	(5x0.20)+(1.205x0.80)	=	2
CI	=	(2-2) /(2-1)	=	0
CR	=	(0/0)	=	0.0

Table 15. Hierarchy Ratio of Indicators in Water Source Variables

Indicators	Hierarchy
Distance to water source	80 %
Capacity of water source	20 %

Table 11 is the conclusion of a comparison of the ratio of hierarchical values between indicators of mass block arrangement of passive protection systems based on the AHP method. The results obtained are that the mass composition parameter in the site has the highest hierarchy with a ratio of 87.5% and then the mass position parameter relative to the road with a ratio of 12.5%.

B. Comparison of Hierarchical Values between Indicators on the Water Source Variable

Table 12 shows a comparison of intensity values between indicators of water source variables. This assessment is carried out by experts. The data obtained from this assessment then input into the criteria comparison matrix table.

Based on Table 13, a priority hierarchy is obtained between indicators on the water source variable of passive fire protection systems in traditional Batak Toba houses.

The water capacity has a hierarchical value of 0.20 and the distance from the building to the water source has a hierarchical value of 0.80.

Table 14 serves to test the validity and reliability of the data. As in Sub-chapter 2.6.1 concerning the stages of the analysis method with AHP, the results are stated to be consistent and valid if the CR or consistency ratio results are ≤ 0.1. From Table 14, the CR results are 0.0. Then the hierarchical results obtained in Table 14 can be declared valid.

Table 15 is a summary of the ratio comparison of hierarchical values between indicators on passive protection system water sources based on the AHP method. The results obtained are that the indicator of the distance to water sources has the highest ratio with a ratio of 80% and then the indicator of the capacity of water sources with a ratio of 20%.

C. Comparison of Hierarchical Values Between Indicators on the Distance Between Buildings Variables

Table 16 shows a comparison of intensity values between indicators of distance between buildings. This assessment is carried out by experts. The data obtained from this assessment is then entered into the criteria comparison matrix table.

Based on Table 17, a priority hierarchy is obtained between indicators of distance between buildings of passive fire protection systems in Traditional Batak Toba settlement. The side spacing has a hierarchical value of 0.75 and the front spacing has a hierarchical value of 0.2.

Table 18 serves to test the validity and reliability of the data. As in Sub-chapter 2.6.1 regarding the stages of the analysis method with AHP, the results are declared consistent and valid if the CR or consistency ratio results are ≤ 0.1. From Table 18, the CR results are 0.0. Then the hierarchical results obtained in Table 18 can be declared valid.

Table 19 is a summary of the ratio comparison of hierarchical values between indicators of the distance between buildings of passive protection systems based on the AHP method. The results obtained are that the side distance indicator has the highest hierarchy with a ratio of 75% and then the front side distance indicator with a ratio of 25%.

D. Comparison of Hierarchical Values between Indicators on Open Space Variables

Table 20 shows a comparison of intensity values between open space indicators. This assessment is carried out by experts. The data obtained from this assessment then entered into the criteria comparison matrix table, and then entered the table matrix comparison criteria.

Based on Table 21, a priority hierarchy is obtained between indicators of open-space passive fire protection systems in Traditional Batak Toba settlement. The open space area has a hierarchical value of 0.75 and surface conditions have a hierarchical value of 0.25.

Table 16. Comparison of Interest Intensity Values between Building Distance Indicators in Batak Toba Traditional House Fire Protection Systems

Intensity of Interest	1	2	3	4	5	6	7	8	9	9	8	7	6	5	4	3	2	1	
Left-right side																			Front side

Table 17. Criteria Comparison Matrix

Criteria	Side	Front side	Eigenvalues		Amount	Average
Left-right Side	1,000	3,000	0.075	0.075	1,500	0.750
Front side	0.333	1,000	0.250	0.250	0.500	0.250
Amount	1,333	4,000				

Table 18. Consistency Test

Lamda Max	=	(1.3x0.75)+(4x0.25)	=	2
CI	=	(2-2) /(2-1)	=	0
CR	=	(0/0)	=	0.0

Table 19. Hierarchy Ratio of Indicators in the Distance between Buildings Variable

Indicators	Hierarchy
Side Distance	75 %
Front Distance	25 %

Table 20. Comparison of Interest Intensity Values between Open Space Indicators in Batak Toba Traditional House Fire Protection Systems

Intensity of Interest	1	2	3	4	5	6	7	8	9	9	8	7	6	5	4	3	2	1	
Area																			Surface Condition

Table 21. Criteria Comparison Matrix

Criteria	Area	Condition Surface	Eigenvalues		Amount	Average
Area	1,000	3,000	0.750	0.750	1,500	0.750
Surface condition	0.333	1,000	0.250	0.250	0.500	0.250
Amount	1,333	4,000				

Table 22 serves to test the validity and reliability of the data. As in Sub-chapter 2.6.1 concerning the stages of the analysis method with AHP, the results are stated to be consistent and valid if the CR or consistency ratio results are ≤ 0.1. From Table 22, the CR results are 0.0. Then the hierarchical results obtained in Table 22 can be declared valid.

Table 23 is a summary of the ratio comparison of hierarchical values between open space indicators of passive protection systems based on the AHP method. The results obtained are that the area indicator has the highest hierarchy with a ratio of 75% and then the surface condition indicator with a ratio of 25%.

E. Comparison of Hierarchical Values Between Indicators on Flammability Variables

Table 24 shows a comparison of intensity values between indicators of the presence of flammable objects. This assessment is carried out by experts. The data obtained from this assessment is then processed in the criteria comparison matrix table.

Based on Table 25, a priority hierarchy is obtained between the indicators for the presence of flammable objects in the passive fire protection system in Traditional Batak Toba settlement. Movable objects have a hierarchical value of 0.125 and immovable objects have a hierarchical value of 0.875.

Table 26 serves to test the validity and reliability of the data. As in Sub-chapter 2.6.1 concerning the stages of the analysis method with AHP, the results are stated to be consistent and valid if the CR or consistency ratio results are ≤ 0.1. From Table 26, the CR results are 0.0. Then the hierarchical results obtained in Table 26 can be declared valid.

Table 22. Consistency Test

Lamda Max	=	(1.333x0.75)+(4x0.25)	=	2
CI	=	(2-2) /(2-1)	=	0
CR	=	(0/0)	=	0.0

Table 23. Hierarchy Ratio of Parameter Hierarchy in the Mass Block Arrangement Indicator

Indicators	Hierarchy
Area	75 %
Surface Condition	25 %

Table 24. Comparison of Interest Intensity Values between Indicators of the Presence of Flammable Objects in the Passive Fire Protection System for Batak Toba Traditional Houses

Intensity of Interest	1	2	3	4	5	6	7	8	9	9	8	7	6	5	4	3	2	1	
Movable Objects																			Unmovable Objects

Table 25. Criteria Comparison Matrix

Criteria	Area	Surface Condition	Eigenvalues		Amount	Average
Movable Objects	1,000	0.143	0.125	0.125	0.250	0.125
Unmovable Objects	7,000	1,000	0.875	0.875	1,750	0.875
Amount	8,000	1.143				

Table 26. Consistency Test

Lamda Max	=	(8x 0.125)+(1.143x0.875)	=	2
CI	=	(2-2) /(2-1)	=	0
CR	=	(0/0)	=	0.0

Table 27. Hierarchy Ratio of Indicators in Flammable Object Indicators

Indicators	Hierarchy
Movable Objects	87.5 %
Unmovable Object	12.5 %

Table 27 is a summary of the ratio comparison of hierarchical values between indicators of the presence of flammability differences in passive protection systems based on the AHP method. The result obtained is that the object indicator that cannot be moved has the highest hierarchy with a ratio of 87.5% and then the object indicator can be moved with a ratio of 12.5%.

3.2. Site Design Reliability in Existing Kampung Ulos Hutaraja-Pardamean

The reliability of the passive protection system in the existing conditions of Kampung Ulos Hutaraja-Pardamean was assessed through a literature review and continued with observations and in-depth interviews. The location of Kampung Ulos Hutaraja-Pardamean is on the west side of the island of Samosir, on the edge of the main Pangururuan road, and directly adjacent to Lake Toba.

The building blocks of Kampung Ulos Hutaraja-Pardamean are concentrated at three points—one block on the north, one on the south, and one on the west. The block with the most building mass is the block on the south side with a total of 25 houses consisting of 18 units in good condition, 1 of a traditional house collapsed, five traditional houses, and one unit of information center building (Figure 4).

On the north side are ten residential units and six units are traditional houses. On the west side, there are four units of traditional houses.

Distance between building houses tradition in Ulos Hutaraja Village no order range between 1.5m-7m. This is also influenced by size neither is the building order.

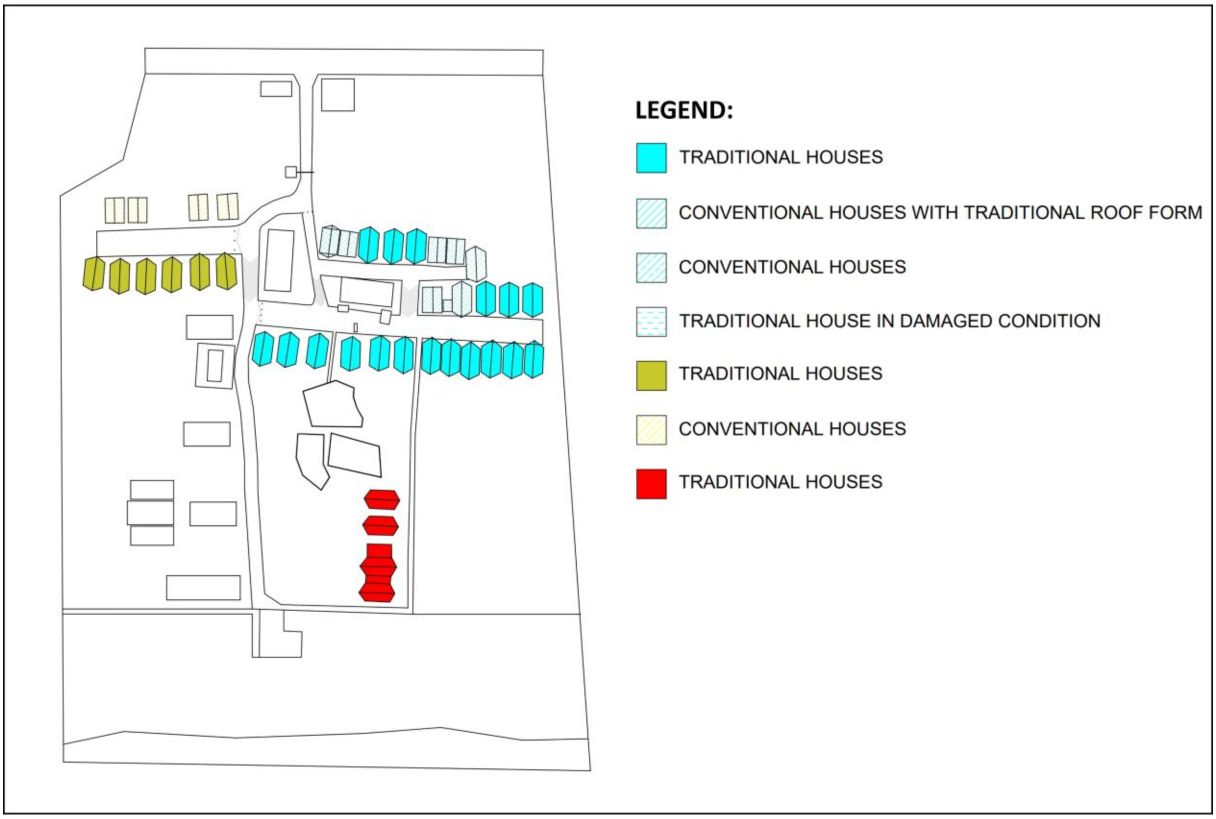
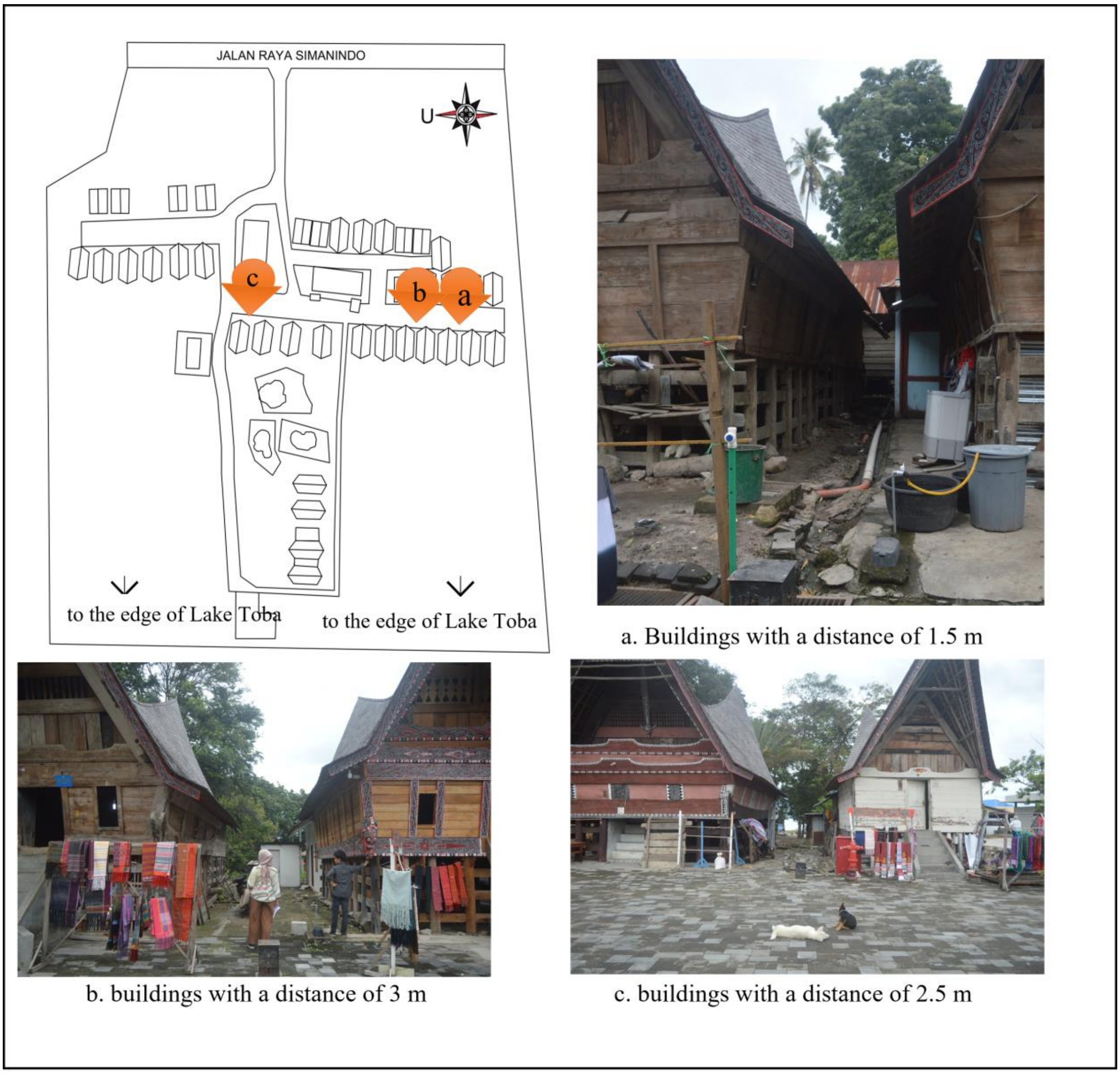


Figure 4. Arrangement of the Kampung Ulos Hutaraja-Pardamean Mass Block



a. Buildings with a distance of 1.5 m

b. buildings with a distance of 3 m

c. buildings with a distance of 2.5 m

Figure 5. Building mass of the South Block of Kampung Ulos Hutaraja-Pardamean

In Figure 5a, the distance of building on the side front is 1.5m and the narrow section behind is 80cm. On the already side, there is extension building main. Two mobs in the buildings in the picture are two masses building with the closest distance between other buildings. In Figures 5b and 5c, the distance of buildings is respectively 2.5m and 3m which are the average distance of the buildings in the block south.

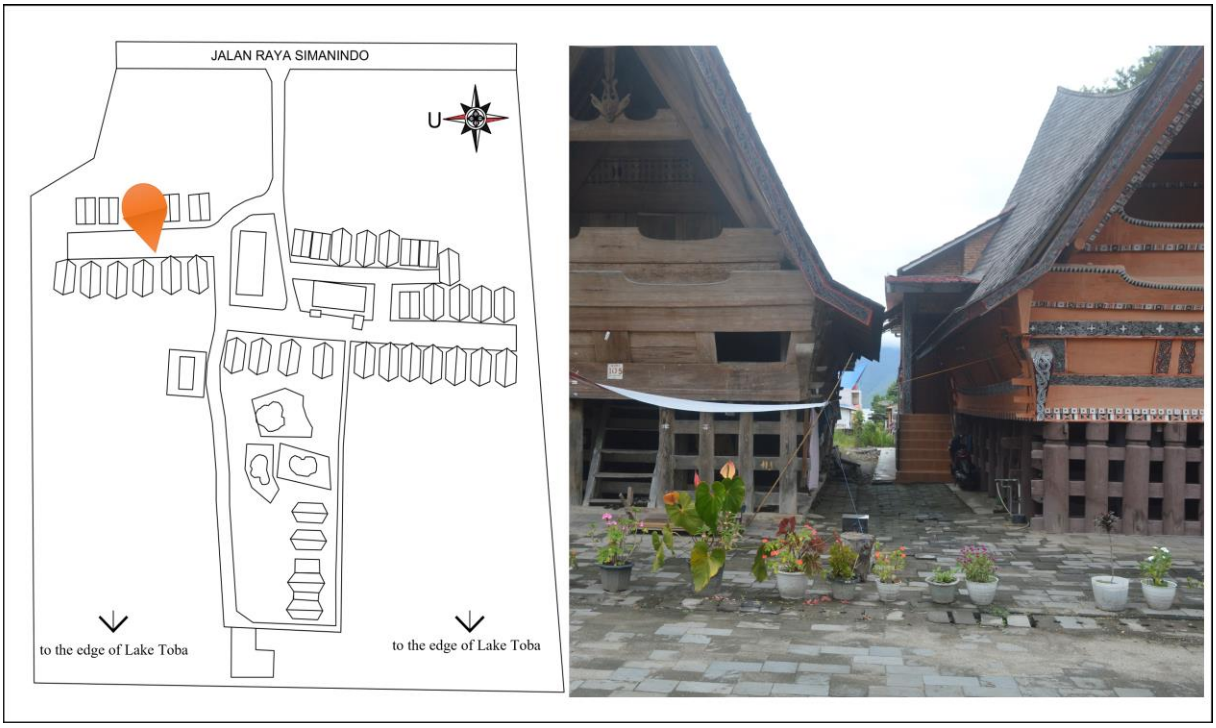


Figure 6. Building Mass of North Block Kampung Ulos Hutaraja - Pardamean

In Figure 6, the distance between buildings is 2m at the front and narrows at the rear to 1m due to the extension buildings.

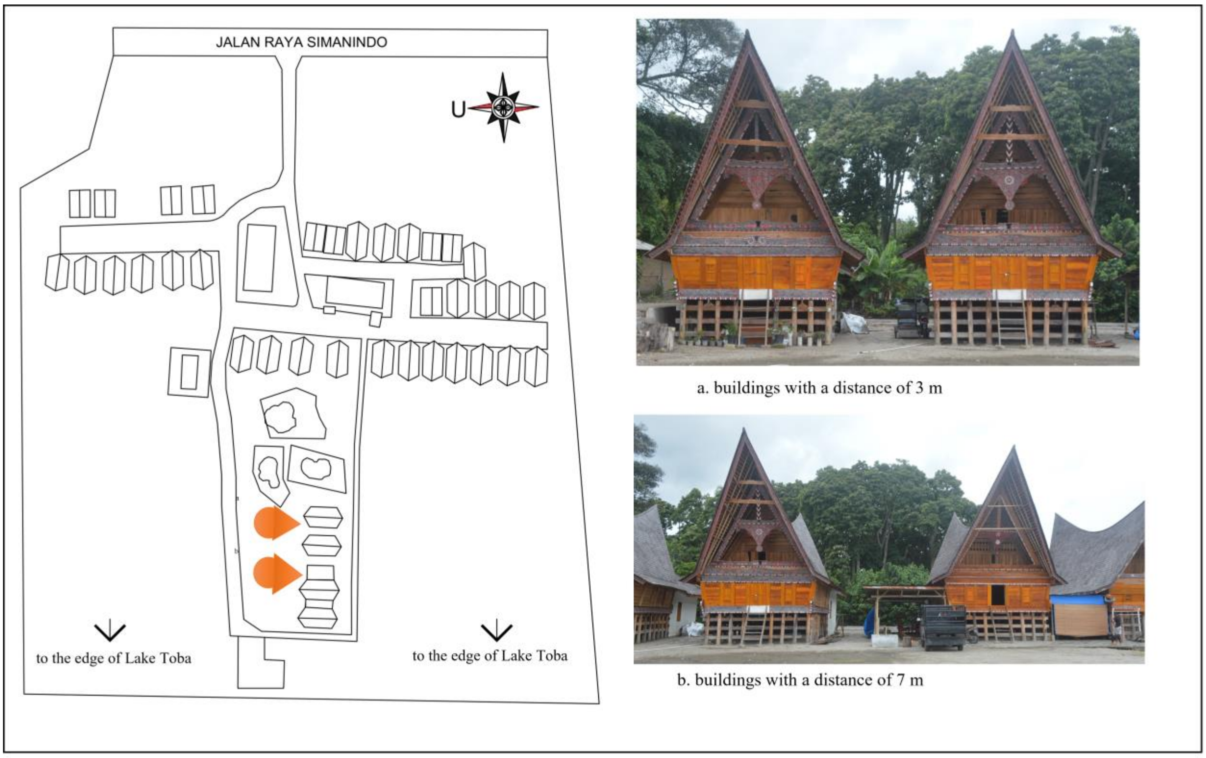


Figure 7. Building mass of the West Block of Kampung Ulos Hutaraja-Pardamean

The mass of buildings in the west block which is a new building, is 4 in a linear arrangement/series, the distance between the buildings is 3.5m, while the distance between the buildings in the center is 7m (Figure 7).

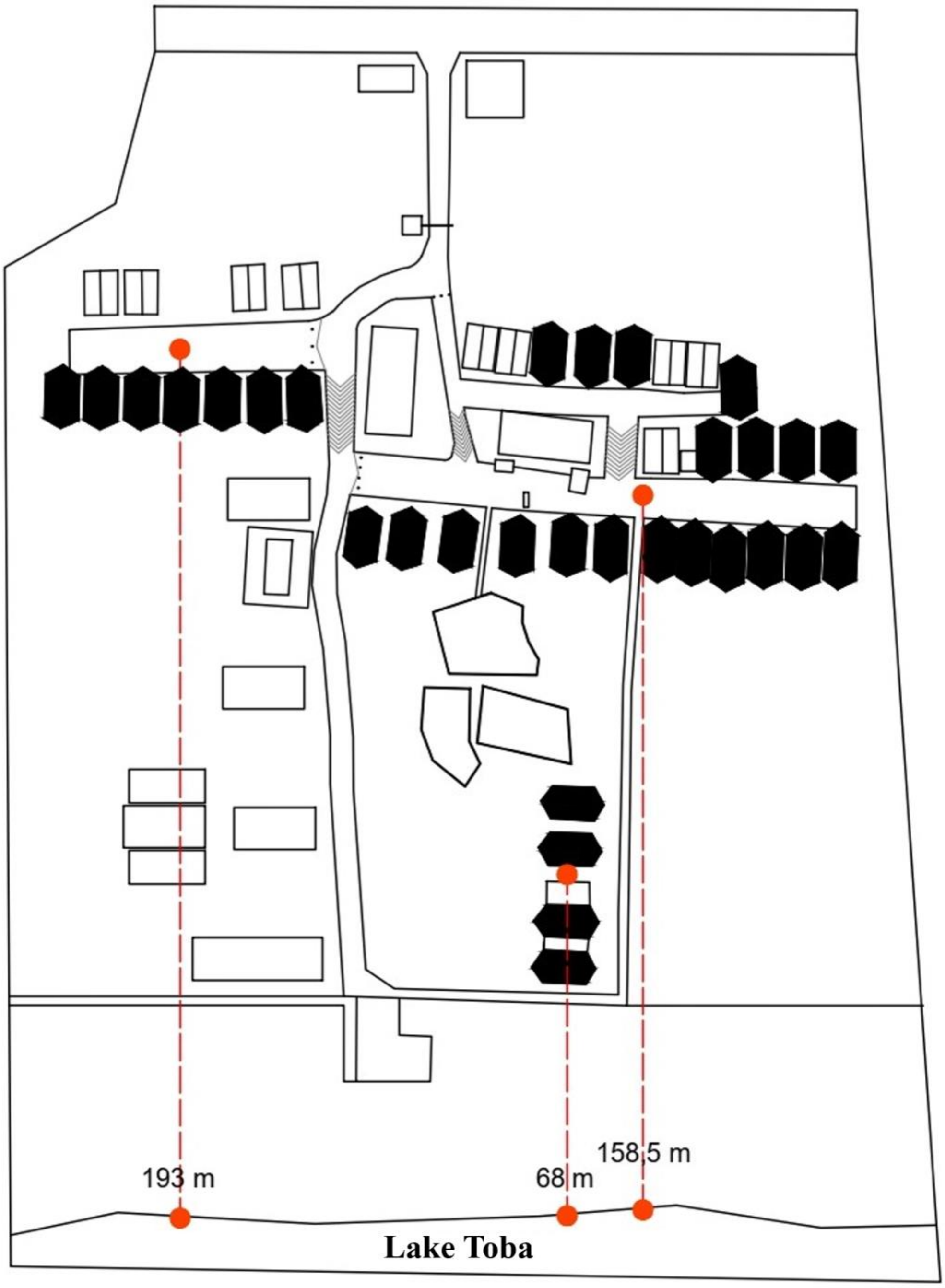


Figure 8. Distance from settlements to water sources in Kampung Ulos Hutaraja-Pardamean

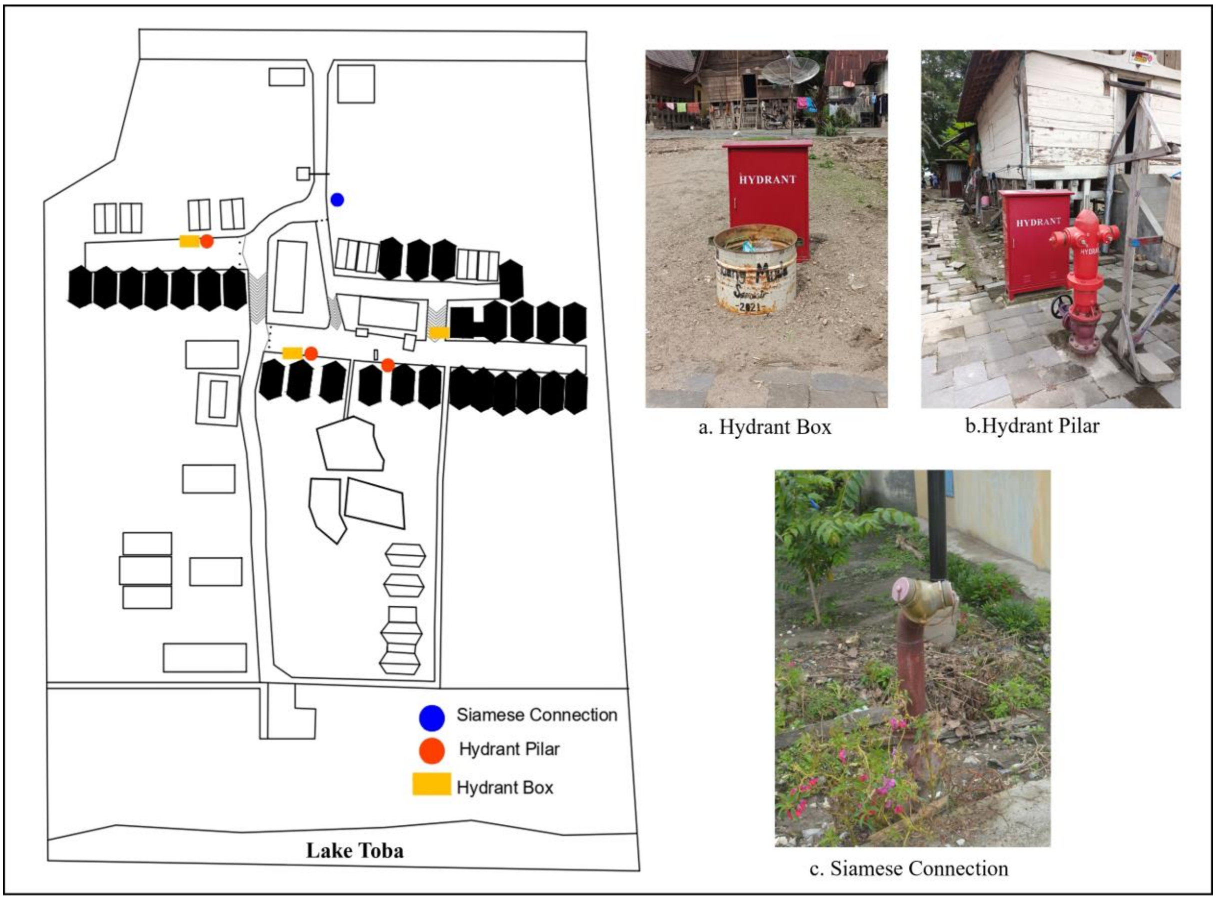


Figure 9. Distance from settlements to water sources in Kampung Ulos Hutaraja-Pardamean

Its position directly adjacent to Lake Toba makes the water supply abundant. But, this housing is adjacent to the swamp side of the lake. The swamp is overgrown with wild plants. So, if it is needed to extinguish a fire, a long pipe is required to reach the deeper side of the lake to get water (Figure 8). The field has three pillar hydrants, three hydrant boxes, and one Siamese connection. However, it cannot be sure whether there is a water supply because it was never checked (Figure 9).

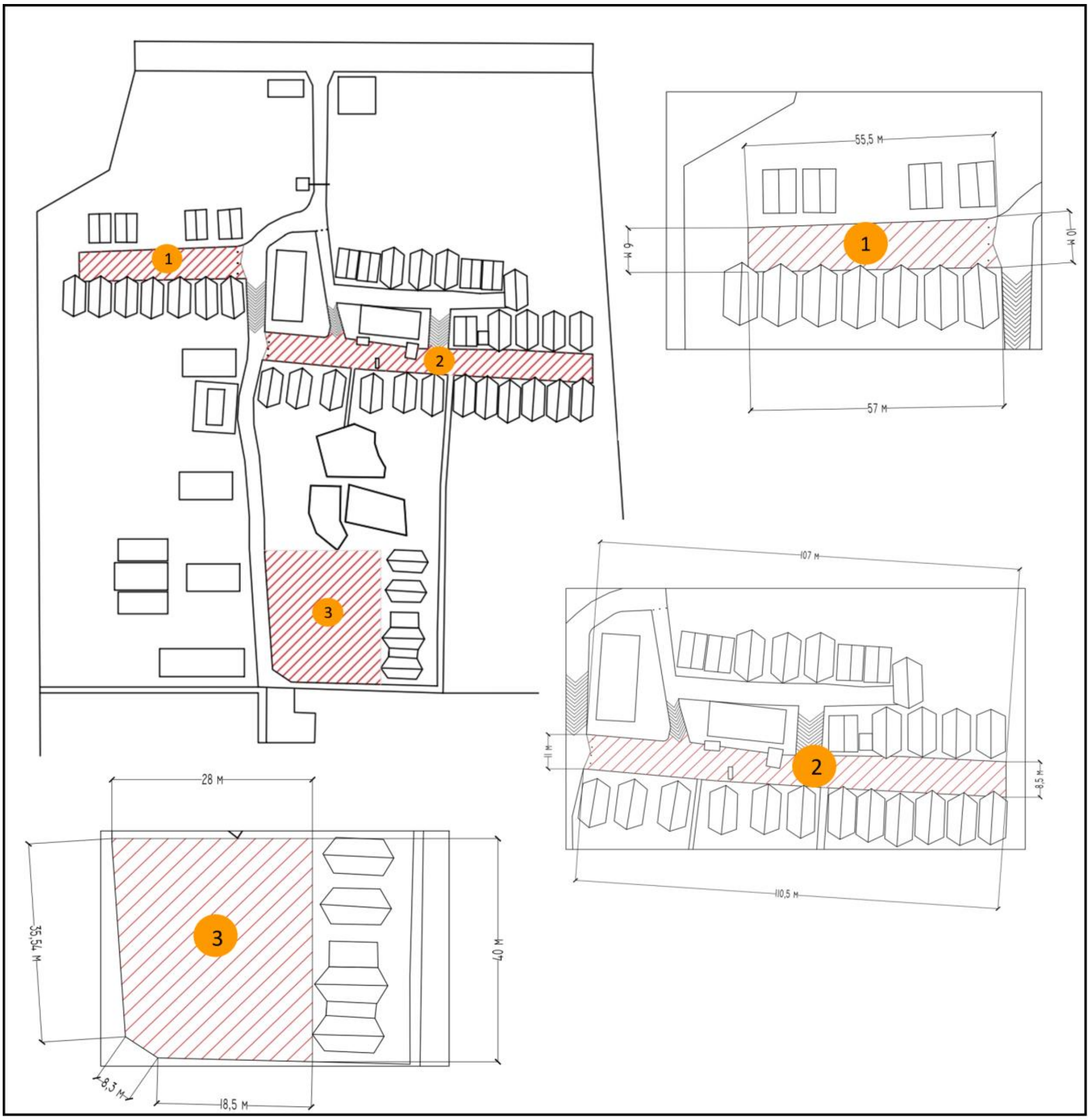


Figure 10. Availability of Open Space in Kampung Ulos Hutaraja-Pardamean

There are four open spaces in the Kampung Ulos Hutaraja-Pardamean area. Three open spaces located in the north, south, and west mass blocks respectively. Others are also on the west side to be precise on the shores of Lake Toba. Initially, the standard of the Batak Toba housing open was the space formed between two rows of traditional houses facing each other that had to lead to Pusuk Buhit. However, over time this conviction began to fade. Open spaces are created according to the needs of the community (Figure 10).

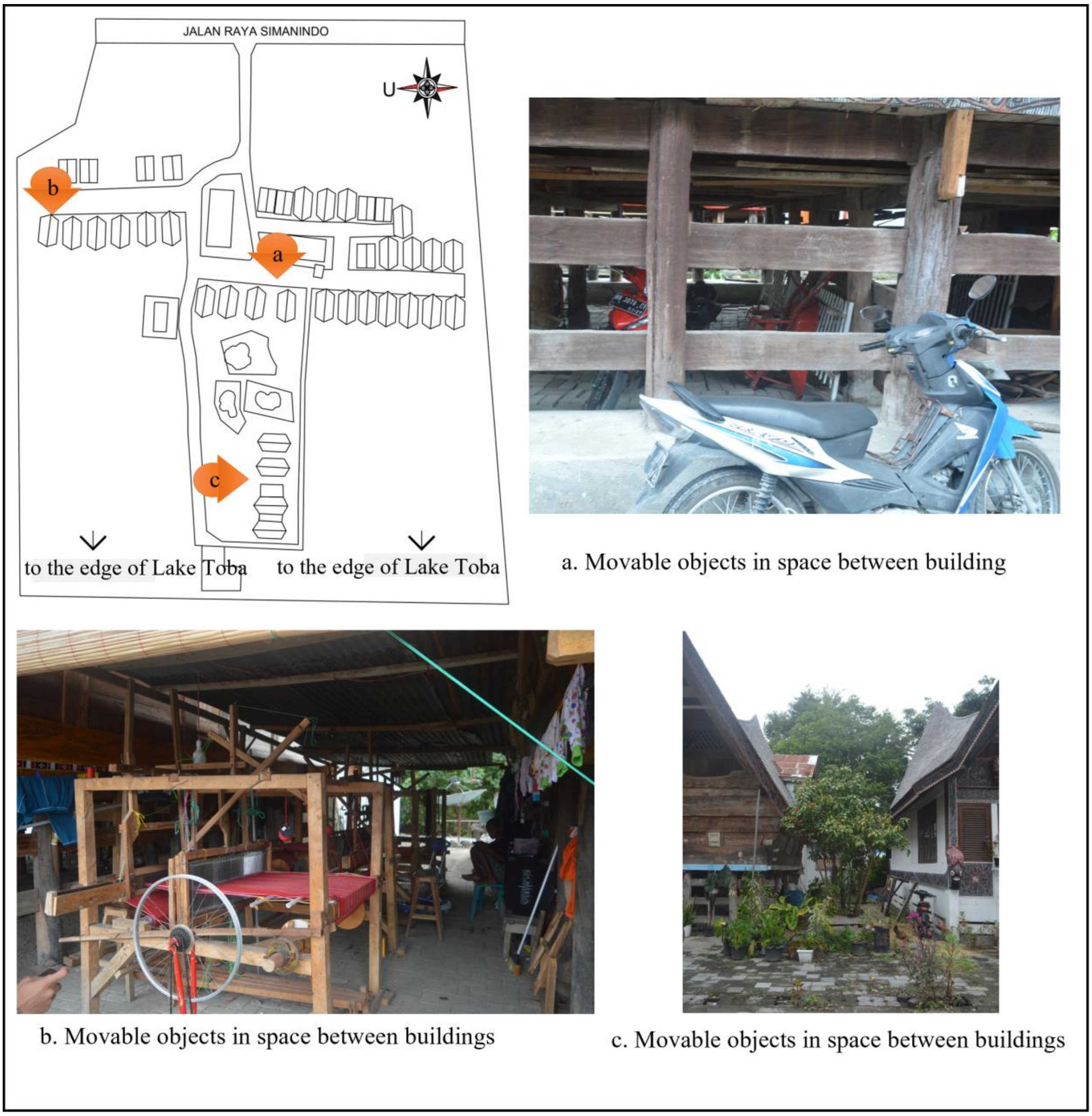


Figure 11. Flammable Objects in Kampung Ulos Hutaraja-Pardamean

The spaces between buildings are used to store vehicles, looms, clotheslines, plants, and so on. It is rare to find agricultural products held by residents. It is caused by the changes in people's livelihoods. Currently, the majority of people work as weavers (Figure 11).

Based on secondary data in the form of a literature review and then analyzed by observing the results of field observations and deep interviews, an ordinal scale assessment was carried out on the quality of the passive protection system at the Kampung Hutaraja site design.

Table 28. Quality Value Protection Passive in Site Design

Variables	Indicators	Scores				Indicators Reliability Value in existing conditions	Variables Reliability Value Ratio in existing conditions	Hierarchy Ratio in Site Design Variables	Variables Reliability Value in existing conditions
		-1	-2	-3	-4		(Indicators Reliability Value in existing conditions: (4 ×number of indicators) ×100%)		(Variables Reliability Value Ratio in existing conditions x Hierarchy Ratio in Site Design Variables)
Mass Block Arrangement	Arrangement mass in site		2			4	50.00%	6.7%	3.35%
	Mass position against road		2						
Building Distance	Side Side	1				5	62.50%	51.4%	32.125%
	Front Side				4				
Water Source	Capacity		2			4	50.00%	22.1%	11.05%
	Distance		2						
Open Space	Area			3		6	75.00%	13.2%	9.9%
	Surface Condition			3					
	Mass position against road		2						
Presence of Flammable Objects	Movable Objects			3		5	62.50%	6.5%	4.0625%
	Unmovable Objects		2						

Legend:

1- None / Very High Risk / Needs Major Repair

2- Yes but not working according to eligibility standards / Moderate-High Risk

3- Yes, meets the standard, but still can be improved / Low Risk

4- Very Good / Perfect.

Table 28 shows the assessment results based on the observations and assessments of the informants. In the mass block arrangement, the composition of the mass on the site and the relative position of the site to the road are considered moderate to high fire risk. In the building distance indicator, the distance between buildings on the left and right sides is too close so that there is a high risk of spreading anything in the event of a fire, while the distance between buildings facing each other is far enough so that it is safe from the risk of fire spreading.

The distance between very close adjacent buildings ranges from 1-3m. Referring to the Decree of the Minister of State for Public Works of the Republic of Indonesia No. 10/KPTS/2000 concerning Technical Provisions for Safeguarding against Fire Hazards in Buildings and the Environment, a safe building distance against the danger of fire is for buildings up to 8 meters high, having a minimum length of 3 meters from each other.

The spread of fire caused by fire spots is not always visible, especially between the burning house and adjacent ones where the released flames are engulfed and immersed in external flames [26]. In addition, based on the results of previous research, it has also been proven that fires that occur in village cultural heritage areas will quickly spread to adjacent houses because the houses are built with wooden structures [28].

In a fire, fire can spread if residences are close enough, mainly due to radiant heat transfer and direct flame emissions. In general, the closer a building is to a nearby fire source, the faster the fire will occur, although ignition time is also determined by the heat flux that arises and the orientation of the residence towards the fire. Several small fires develop into large fires due to the layout of the settlement [23].

Rearranging the distance between buildings to existing conditions is not possible. So, there needs to be a protection mechanism to prevent the spread of fire, for example, by providing coating material or a cooling mechanism with water while the distance between facing buildings is far enough so that it is safe from the risk of fire spreading.

On the water source indicator, the available water capacity is considered to exist but does not meet the standard; the distance is also considered inadequate because the shores of Lake Toba, which is directly adjacent to Kampung Ulos Hutaraja-Pardamean, are swamps, so a long fire hose is needed to reach a lake area that is deep enough to suck water into the tank so that sand and weeds are not carried into the fire unit tank and cause damage.

Water supply for fire fighting purposes can be obtained from natural sources such as water pools, lakes, rivers, rapids, deep wells, and irrigation canals or artificial ones such as water tanks, gravity tanks, swimming pools, fountains, reservoirs, water tankers and hydrants. If the water supply comes from a natural source, it must be equipped with piping/water suction equipment (drafting point). The water surface in natural sources must be guaranteed to be utilized or used during dry conditions. Apart from the water supply coming from natural sources, it can also come from hydrants provided in the environment, and the city government is obliged to provide and maintain city fire hydrants. Hydrant water for fire extinguishing may not be subject to fees/charges [17].

In the Open Space Indicator, the area parameter is considered to meet the standard and the surface conditions that already use paving blocks in the form of pavement. On the indicator of the presence of flammable objects, the parameter of flammable movable objects is in a low level of risk of burning, while the parameter of the unmovable flammable objects, such as vines and trees, is at a moderate to high level of risk.

4. Conclusions

The site design has five variables: distance between buildings, air sources, open space, arrangement of mass blocks, and presence of flammable objects. Each variable has indicators. The indicators of the variable distance between buildings are the sides and the front side, the indicators of the air source variables are capacity and length, the indicators of the open space variables are the area and surface conditions, the indicators of the mass block arrangement variable are the arrangement of the masses in the location and the position of the buildings to the road, indicators of the variable presence of flammable objects are movable objects and immovable objects.

Based on an assessment of the existing conditions of the Traditional Batak Toba Settlement, Kampung Ulos Hutaraja-Pardamean data was obtained with the result that the building distance variable has a variable priority hierarchy of 51.4% and the ratio of the reliability value of the existing variable is 62.5%, so the ratio value of the existent variable is 32.125%, water sources have a priority hierarchy variable is 22.1% and the ratio of the reliability value of the existing variable is 50%, so the ratio of the existent variable's value is 11.05%, Open Space has a variable priority hierarchy of 13.2% and the ratio of the existing variable's reliability value is 75%, so the ratio of the existent variable's value is 9.9%, Mass Block Arrangement has a variable priority hierarchy of 6.7% and the ratio of the reliability value of the existent variable is 62.5%, so the ratio of existing variable values is 3.35%, and the last variable, namely the Presence of Flammable Objects, has a variable priority hierarchy of 6.5% and the ratio of the reliability value of the existing variable is 62.5%, so the ratio of the existent variable value is 4.0625%. Based on these findings, it was found that the reliability level of the passive protection system at the existing site design was 67.085%, which means that the reliability conditions are good enough, but optimization still needs to be done.

Among the five Site Design variables that have the most significant impact on the fire protection system of the Batak Toba Traditional House is the distance to the building, which has a hierarchy of 51.04%. It means that a significant impact will occur if optimization efforts are at the variable distance between buildings compared to optimization efforts at other variables. The advanced stages can be optimized sequentially based on a variable hierarchy from the highest to the lowest.

It is recommended to provide alternative routes to create water reservoirs, construct pavements on surfaces that are still soil, and arrange vines.

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REFERENCES

[1] J. Xin, C. F. Huang, E. Management, and J. Xin, "Fire Risk Assessment of Residential," 2013, doi: 10.1007/s10694-013-0327-8.

[2] C. Yuan, Y. He, Y. Feng, and P. Wang, "International Journal of Disaster Risk Reduction Fire hazards in heritage villages : A case study on Dangjia Village in China," *Int. J. Disaster Risk Reduct.*, vol. 28, no. August 2017, pp. 748–757, 2018, doi: 10.1016/j.ijdrr.2018.02.002.

[3] A. Y. Permana, I. Susanti, and K. Wijaya, "Kerentanan Bahaya Kebakaran di Kawasan Kampung Kota. Kasus: Kawasan Balubur Tamansari Kota Bandung," *J. Arsit. Zo.*, vol. 2, no. 1, p. 32, 2019, doi: 10.17509/jaz.v2i1.15208.

[4] A. N. Lisianti, M. Lestari, and A. Ainy, "Kitchen Safety Behaviour Sebagai Upaya Preventif Kebakaran di Lingkungan Rumah Tangga," *J. Kesehat.*, vol. 11, no. 2, pp. 19–24, 2018, doi: 10.23917/jk.v11i2.7665.

[5] Y. Hesna, B. Hidayat, and S. Suwanda, "Evaluasi penerapan sistem keselamatan kebakaran pada bangunan gedung rumah sakit dr. m. djamil padang," vol. 5, no. 2, pp. 65–76, 2009.

[6] B. J. Meacham, D. Charters, and P. Johnson, *Building Fire Risk Analysis*. 2016. doi: 10.1007/978-1-4939-2565-0.

[7] S. Durak, Y. Erbil, and N. Akıncıtürk, "Sustainability of an Architectural Heritage Site in Turkey : Fire Risk Assessment in Misi Village," vol. 3058, 2011, doi: 10.1080/15583051003642721.

[8] N. A. Hamzah, "Situational Analysis on Safety and Health in Primary School in Kota Bharu," *J. Community Health*, no. 2, 2009.

[9] T. Okubo, "Traditional wisdom for disaster mitigation in history of Japanese Architectures and historic cities," *J. Cult. Herit.*, vol. 20, pp. 715–724, 2016, doi: 10.1016/j.culher.2016.03.014.

[10] V. Rahman, "Kajian Penerapan Sistem Proteksi Pasif Desain Site Planing Pada Beberapa Kasus Rumah Susun," *Repos. Institusi Univ. Sumatera Utara*, pp. 1–18, 2003.

[11] L. G. F. Salazar, X. Romão, and E. Paupério, "Review of vulnerability indicators for fire risk assessment in cultural heritage," *Int. J. Disaster Risk Reduct.*, vol. 60, no. April, 2021, doi: 10.1016/j.ijdrr.2021.102286.

[12] A. Thomas, K. Moinuddin, H. Zhu, and P. Joseph, "Passive fire protection of wood using some bio-derived fire retardants," *Fire Saf. J.*, vol. 120, no. May, p. 103074, 2020, doi: 10.1016/j.firesaf.2020.103074.

[13] A. H. Buchanan, "Fire performance of timber construction," *Prog. Struct. Eng. Mater.*, vol. 2, no. 3, pp. 278–289, 2000, doi: 10.1002/1528-2716(200007/09)2:3<278::aid-pse33>3.3.co;2-g.

[14] L. Lowden and T. Hull, "Flammability behaviour of wood and a review of the methods for its reduction," *Fire Sci. Rev.*, vol. 2, no. 1, p. 4, 2013, doi: 10.1186/2193-0414-2-4.

[15] A. H. Buchanan and A. K. Abu, *Structural Design For Fire Safety*, Second. West Sussex: Wiley, 2017.

[16] B. A. L. Östman, "Fire performance of wood products and timber structures," *Int. Wood Prod. J.*, vol. 8, no. 2, pp. 74–79, 2017, doi: 10.1080/20426445.2017.1320851.

[17] P. Kementrian, "Kementerian PUPR Mulai Penataan Kampung Ulos Samosir," *Kementrian PUPR*, 2020. https://pu.go.id/berita/kementerian-pupr-mulai-penataan-kampung-ulos-samosir

[18] W. K. Chow, "Building fire safety in the far east," *Archit. Sci. Rev.*, vol. 48, no. 4, pp. 285–294, 2005, doi: 10.3763/asre.2005.4836.

[19] M. Kim, B. Kim, M. Kim, and H. Lim, "Case Studies on different software tools for Numerical Modeling of Passive Fire Protection," *Trans. Korean Nucl. Soc. Autumn Meet.*, pp. 25–27, 2018.

[20] D. P. Nolan, "Philosophy of Protection," *Fire Pump Arrange. Ind. Facil.*, pp. 11–15, 2017, doi: 10.1016/b978-0-12-813043-8.00002-6.

[21] Suprapto, "Sistem Proteksi Kebakaran Pasif Kaitannya Dengan Aspek Keselamatan Jiwa (Passive fire protection and life safety)," vol. 2, no. 2, 2007.

[22] Menteri Pekerjaan Umum, *Peraturan Menteri Pekerjaan Umum Nomor : 26/PRT/M/2008 Tentang Persyaratan Teknis Sistem Proteksi Kebakaran Pada Bangunan Gedung dan Lingkungan*. Indonesia, 2008.

[23] S. Stevens, L. Gibson, and D. Rush, "Conceptualising a GIS-based risk quantification framework for fire spread in informal settlements: A Cape Town case study," *Int. J. Disaster Risk Reduct.*, vol. 50, no. March, p. 101736, 2020, doi: 10.1016/j.ijdrr.2020.101736.

[24] D. Nurmayadi and M. S. Al Huseiny, "Peningkatan Kualitas Keandalan Sarana dan Prasarana Sistem Proteksi Kebakaran Pasar Tradisional di Kota Tasikmalaya," pp. 163–169, 2018.

[25] B. Kumar and S. Bhaduri, "International Journal of Disaster Risk Reduction Disaster risk in the urban villages of Delhi," *Int. J. Disaster Risk Reduct.*, no. August 2017, pp. 1–17, 2018, doi: 10.1016/j.ijdrr.2018.04.022.

[26] K. Himoto, M. Shinohara, A. Sekizawa, K. ichi Takanashi, and H. Saiki, "A field experiment on fire spread within a group of model houses," *Fire Saf. J.*, vol. 96, no. March 2018, pp. 105–114, 2018, doi: 10.1016/j.firesaf.2018.01.003.

[27] S. Park, N. Mishima, and Y. Kwon, "Simulation Study on the Fire Safety of AsanOeam Folk and JeonjuHanok Village," *Proc. Korea Contents Assoc. Conf.*, pp. 259–260, 2016.

[28] D. Sweetman, M. Badiee, and J. W. Creswell, "Use of the transformative framework in mixed methods studies," *Qual. Inq.*, vol. 16, no. 6, pp. 441–454, 2010, doi: 10.1177/1077800410364610.

[29] Sugiyono, *Metode penelitian pendidikan*. 2008.

[30] A. A. Hidayat, *Menyusun Instrumen Penelitian & Uji Validitas Reliabiltas*, 1st ed. Surabaya: Health Books Publishing, 2021.